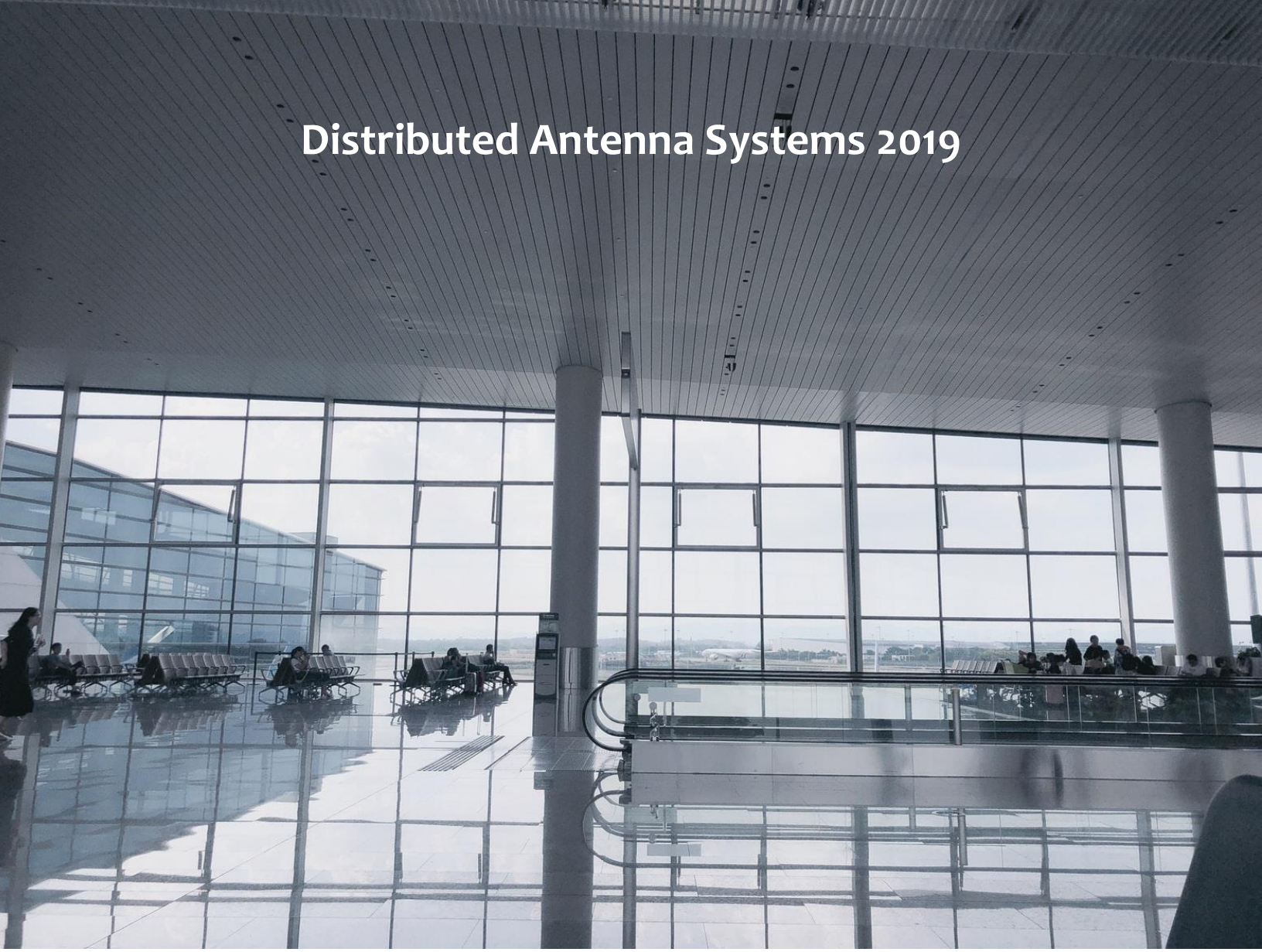
Distributed Antenna Systems 2019



Abstract: **This report provides a detailed view of the DAS market, with technical information on architectural changes, as well as a close look at business metrics related to operator and enterprise investments in DAS projects. New options are considered as the Public Safety market ramps up, and DRS systems such as LampSite and Radio Dot compete with DAS by offering multi-operator solutions. A five-year forecast takes these key factors into account.**

Kyung Mun
October 2019

MOBILE EXPERTS

MOBILE EXPERTS

MEXP-DAS-19

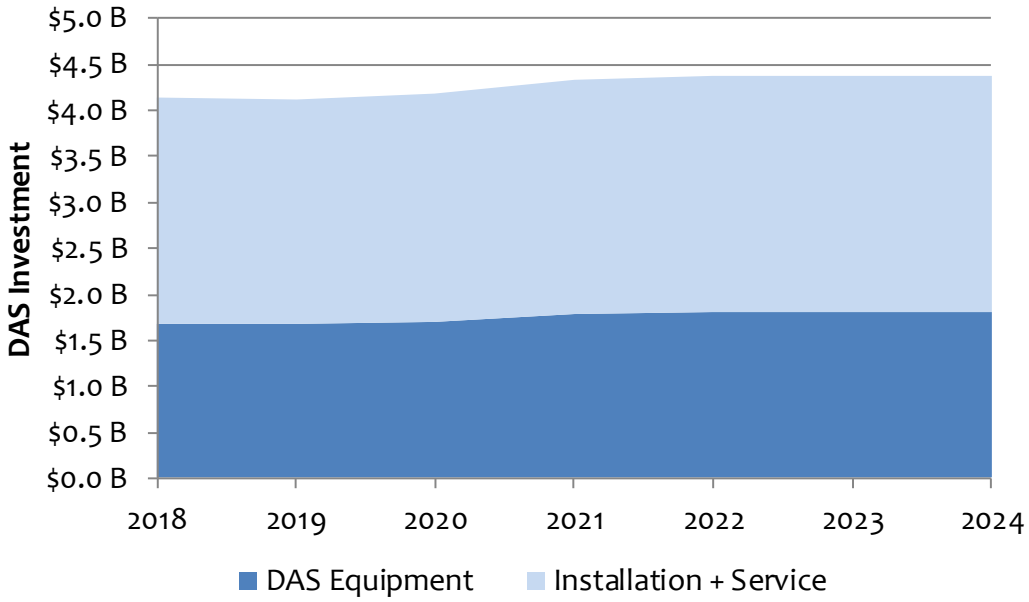
TABLE OF CONTENTS

CHARTS

FIGURES

1. EXECUTIVE SUMMARY

The Distributed Antenna System (DAS) industry has been in transition to expand beyond carrier-driven DAS opportunities at large public venues like stadiums and airports to enterprise-focused opportunities in commercial buildings for several years. While Carrier DAS opportunities from new construction come up from time to time, they are fewer and more heavily competed for nowadays. Meanwhile, the Enterprise DAS market uptake has not been big enough to offset the decline in carrier in-building spend. As a result, the DAS market has been declining over the past couple of years. With the replacement cycle picking up, the indoor DAS market is beginning to turn around and is expected to see a moderate growth at 2% CAGR from 2018 through 2024 as operators deploy mid-band (3-6 GHz) spectrum for 5G indoors. The DAS architecture embodying the neutral-host business model will be a preferred model as indoor networks transition to 5G.



Source: Mobile Experts

Chart 1: Global DAS Market Size, including Service & Installation, 2018-2024

While DAS is favored in North America and Europe, the Distributed Radio System (DRS) small cells (e.g., Huawei LampSite, Ericsson Radio Dot, etc.) driven by Tier-1 vendors are becoming the preferred in-building wireless solution in China and parts of Asia where the operators make direct investments in indoor projects rather than through neutral host providers. Including DAS and DRS, the total in-building wireless equipment market is forecasted to grow faster at over 4% CAGR from 2018 to $3.6B in

2024. Including installation and services, the total in-building wireless investment spends reach between $7B - $9B during the forecast period from 2018 to 2024.

In the midst of LTE to 5G transition in operator networks, the DAS industry is grappling with multiple challenges ranging from competing architectures (DRS small cells, Open RAN), spectrum alternatives (CBRS, mid-band, millimeter wave), and business model choices (carrier-direct, neutral host, system integrator channels, or enterprise-direct). The broader in-building wireless market is changing, and the DAS suppliers have been expanding their product portfolios, such as small cells, open virtualized RAN, CBRS radios, etc., in anticipation of "what's next."

Mobile Experts believe that the traditional DAS architecture, which embodies the "neutral host" business model, will remain fairly stable in addressing the Carrier DAS market mostly in high-density, large public venues like stadiums and airports. Also, we see a bright future for Tier-1 driven DRS solutions in "carrier-dominant" markets like China where the neutral-host infrastructure sharing is not commonplace. Meanwhile, Open RAN (ORAN) virtualized solutions offer an exciting opportunity for the traditional DAS suppliers to potentially create combined "coverage" and "capacity" solutions that can scale across different market segments.

The DAS industry isn't dead and will be around for a while. But, it is evolving. The ORAN initiatives offer an opportunity to create new indoor solutions that can evolve from LTE to 5G and provide scalable capacity and coverage solutions for the Enterprise DAS market that we have been talking about for some time.

With the different challenges and evolution underway, in 2020 Mobile Experts will be changing the scope of our *DAS* report to *In-Building Wireless* in acknowledgement that the indoor solutions will range widely from repeaters, small cells, DRS, ORAN, and DAS for the wide range of in-building segments. This is our last *DAS* report, but please look out for the next year's *In-Building Wireless* report which will encompass a broader scope of indoor challenges, product solutions, and evolving business models associated with bringing 5G indoors.

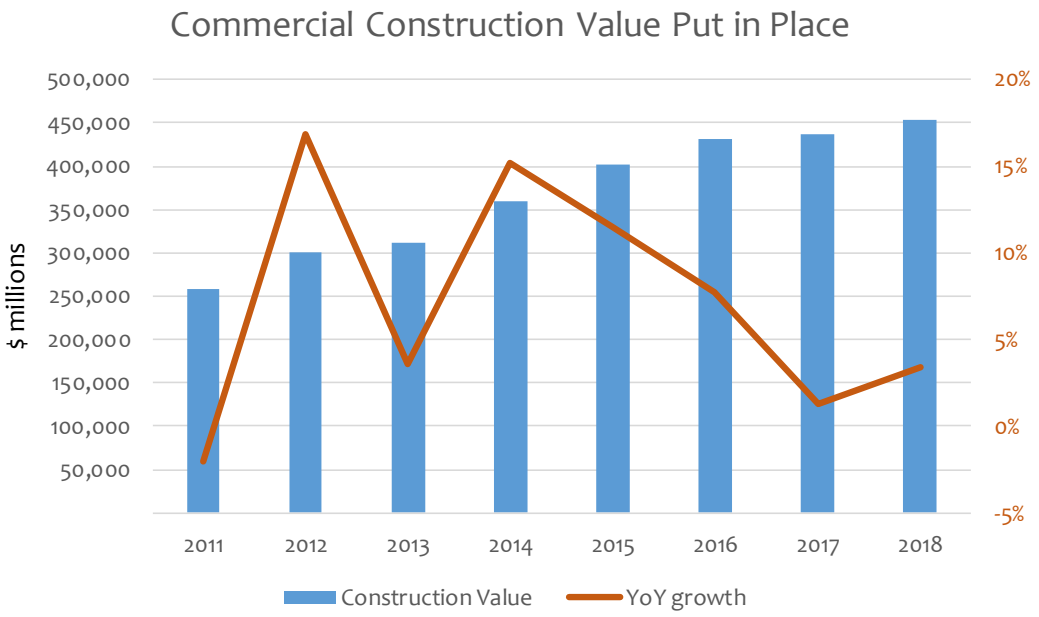
2. MARKET OVERVIEW

The underlying market drivers for DAS, or in-building wireless solutions in general, remain strong. The growing mobile traffic continues to go up, and the Private LTE trend among certain industry verticals are providing tailwind support for indoor cellular coverage solutions. While the past couple of years has been tough for major DAS vendors, the market is seeing some uptick trends from the replacement cycle at large venues where DAS remains the key solution to solving indoor cellular challenges. The technology, spectrum, and business model alternatives, such as Open RAN (ORAN), virtualized baseband, CBRS, C-band, and millimeter wave spectrum, are expanding the DAS ecosystem to enable a whole host of new and hybrid in-building wireless solutions and setting the stage for bringing 5G indoors. Meanwhile, the Public Safety market continues to provide an incremental market opportunity for some DAS vendors.

DAS Growth from Replacement Cycle

The DAS market has been tough for top OEM vendors for the past couple of years as the uptake in the Enterprise DAS has not been enough to offset the decline in operator spends on indoor projects. For instance, major construction boom in commercial space in the USA has largely peaked according to the US Census.[1] With most major public venues like stadiums and airports largely covered with DAS and other in-building wireless solutions, new DAS projects have been fewer and far in-between.

[1] The *value of construction put in place* is used as a proxy for construction activity. According to the US Census, it refers to a measure of the value of construction installed or erected at the site during a given period, including costs of materials and labor, contractor's profit, architectural and engineering work, and miscellaneous overhead costs.



Source: US Census

Figure 1. Growth in Construction Spend in the USA Has Slowed

As the market transitions from new construction projects like new sports stadiums and transportation hubs to replacement or upgrade projects driving large projects, we see positive signs in the large venue segment. With increasing cellular traffic volume reported at each successive Super Bowl events[2], it is no surprise that DAS replacement cycle is shrinking (to 4-5 years now) as high-density venues like NFL stadiums in the United States are now being designed for about 200 sectors from 100 sectors today!

Private LTE "Tailwind"

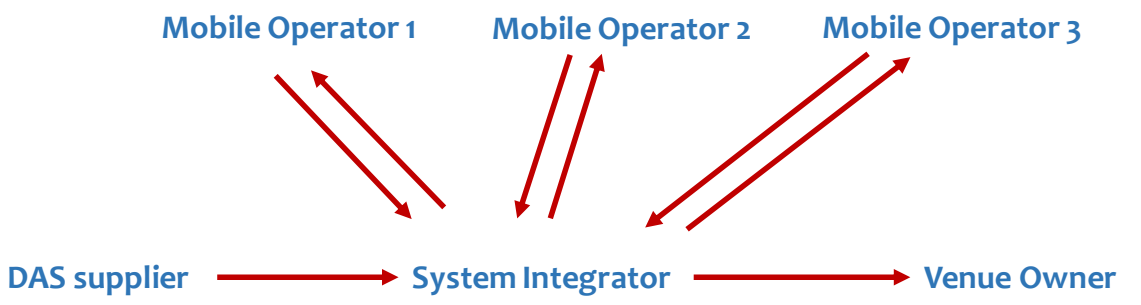
Besides the traditional market drivers like new venue constructions and mobile broadband traffic growth, the Private LTE trend to enable higher quality wireless connectivity at enterprise venues for mission-critical applications like industrial automation is driving demand for indoor cellular solutions like DAS and other in-building wireless technologies. While Wi-Fi is used as the primary wireless broadband connectivity at most enterprises, there is a growing acknowledgment that certain mission-critical applications require deterministic LTE and 5G links, for example in large oil & gas and mining fields or smart factories.

[2] AGL, https://www.aglmediagroup.com/super-bowl-mobile-data-usage-takes-carriers-back-to-the-future/, Feb 12, 2015

Figure 2. Private LTE applications drive Indoor and Outdoor Cellular Systems

Impact of CBRS Spectrum Alternative

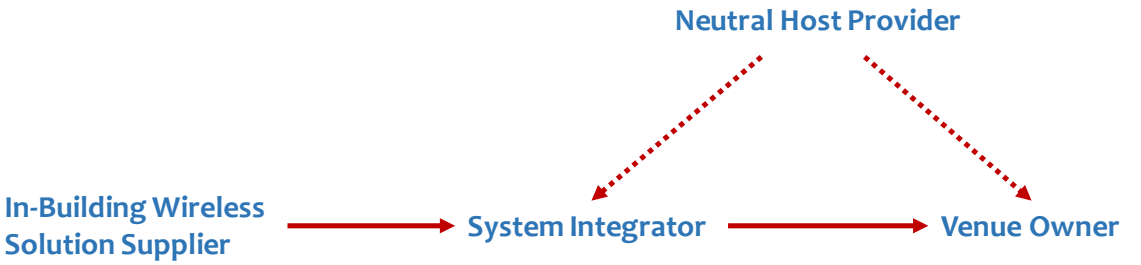
New shared spectrum alternatives like CBRS are raising interest in Private LTE. With the possibility of spectrum ownership directly available to enterprises or neutral-host operators, the complex web of stakeholders and process of securing signal sources can be simplified and make indoor LTE deployments quicker. Today, securing a signal source can be a drawn-out process involving legal and network departments at operators and multiple stakeholders including system integrators, venue owners, and neutral-host providers. As shown below, a system integrator can be involved in lengthy negotiations with multiple network operators to secure signal sources. This process can take several months even after completing DAS installation which can be hard to explain to irate venue owners who may be frustrated with delays.



Source: Mobile Experts

Figure 3. Typical DAS Deployment Process

With direct spectrum ownership like CBRS, it is possible for a venue owner, or in conjunction with a neutral host provider, to work with a system integrator and an in-building wireless solution supplier to deploy an indoor system much more quickly without involving the mobile operators. Over the longer term, the Private LTE networks can be leased out to mobile operators for traffic offload at key venues.



Source: Mobile Experts

Figure 4. Simplified In-Building Deployment Process with Spectrum Ownership

Based on our estimate, the total PAL proceeds costs in tens of millions of dollars in the top 50 counties except for Los Angeles County which is much higher due to its large geographic footprint and high population density.[3] Based on our initial analysis, we don't expect the CBRS PAL spectrum costs to impede aspiring neutral host providers or large enterprises who seek to develop enterprise-class LTE networks for private use in the near term and public cellular services in the long term.

The CBRS initial commercial deployment has started, and we are seeing several Private LTE use cases. For example, American Dream Meadowlands is a shopping mall in New Jersey that is leveraging CBRS network to handle traffic management outside the large retail and entertainment complex. Over time, we expect these CBRS networks to be used for operator traffic offload at key venues like the American Dream which is nearby a major transportation hub and a sports stadium.

[3] CBRS PAL Spectrum Valuation report, May 2019.

Indoor CBRS networks leveraged for Private LTE use cases can someday become neutral-host mobile offload network for the operators. It is reasonable to expect DAS or some other In-building Wireless solution to provide one or two licensed band plus the CBRS band to satisfy capacity need at most facilities.

Impact of Open RAN (ORAN) and Virtualized RAN (vRAN) Alternatives

In addition to new spectrum alternatives like CBRS, new radio technology like Open RAN (ORAN) and virtualized baseband offerings are creating new opportunities to piece together optimized indoor coverage and capacity solutions for different types of venues and applications. As the in-building wireless (IBW) market transitions from large venue projects, characterized by macro base station fed DAS systems, to enterprise venues with myriad application requirements, we see a rise in hybrid IBW solutions that leverage different combinations of "coverage" (e.g., DAS, small cell, or booster) and "capacity" (i.e., Macro base station, centralized or virtualized RAN baseband) solutions.

The ORAN architecture provides an opportunity to partition the indoor radio network components into different pieces (i.e., Control Unit, Data Unit, and Radio Unit), based on the tradeoff of transport and channel bandwidth. While we see the operator's intention to drive interoperability in eCPRI fronthaul specification through Open RAN Alliance, it remains to be seen how successful they will be. Prior history in CPRI interface has shown that the operators were unsuccessful in keeping the CPRI interface interoperable as vendors were able to keep certain aspects in operation and management layers proprietary. Based on initial feedback from vendors and operators on ORAN development, it appears that the operators are keeping up the pressure on radio OEM vendors to "open up" their interfaces to keep the interoperability intact.

Ultimately, we expect the ORAN and virtualized baseband solutions can bring cost-effective and scalable in-building wireless solutions – if the operators are successful in bringing a fully interoperable eCPRI fronthaul interface. Virtualized baseband solutions like that of JMA Wireless' XRAN or Comba's "5G Cloud Small Cell" solutions can bring competition to lower-profile venues (outside of major public venues like airports and stadiums).

Impact of Business Model Alternatives like Neutral Host Operators

As noted previously, the DAS industry or wider indoor cellular market is undergoing a major transition in several areas. Spectrum alternatives like CBRS and technology shift to "Open" RAN are bringing new technology solutions that can potentially offer more cost-effective solutions to address the segments of the indoor cellular market

that have been prohibitive with traditional DAS offering and business models. These changes are exciting investors to look at the indoor market opportunity more closely. With the macro transition to 5G and indoor challenges of bringing cellular coverage indoors especially into new buildings with building materials that are unfriendly to RF propagation from outside-in, it is natural for investors to see an opportunity. With lots of capital seeking yield in today's low-interest-rate environment, we are observing more and more investors putting money down on infrastructure plays whether they are for tower, fiber, and data center companies. For a certain segment of these capital inflows, we see neutral host operators benefiting from this investment trend.

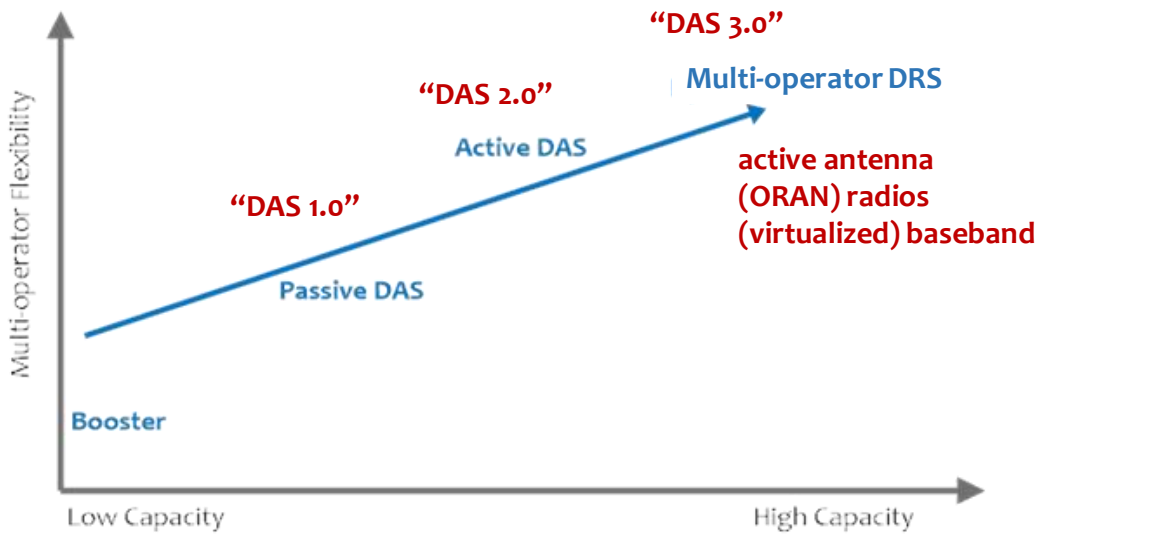
Neutral host operators like Boingo and Extenet essentially act as a managed service provider for venue owners. Sometimes, they take on the primary role of working with system integrators for in-building wireless (IBW) system deployment and operating and managing the network. For example, Boingo has been managing Wi-Fi networks at major airport and transportation venues for many years. It is now a major DAS network operator at the same venues, in addition to Wi-Fi, as it sees strong interest among operators to offload their subscriber traffic onto DAS and Wi-Fi networks at key venues like the airports. With CBRS spectrum ownership, neutral host operators have the potential to expand their LTE capacity indoors while leasing this LTE capacity as secondary carriers to mobile operators. In this arrangement, the mobile operators can manage the quality of their subscribers through licensed carriers on DAS with CBRS channels for user plane data.

DAS and Other In-Building Wireless Solutions

DAS is synonymous with indoor cellular coverage solutions that provide "multi-operator, multi-band, and multi-technology" support. In other words, it is inherently a neutral-host platform. DAS essentially hides the complexity of distributing cellular signals across multiple bands (e.g., AWS, PCS, etc.) and technologies (e.g., 3G, LTE, etc.) of multiple operators with a single platform. With each succession of DAS evolution as illustrated below, DAS vendors have incorporated additional capabilities and domain expertise to enhance DAS solutions for ever-increasing challenges of solving indoor cellular challenges.

The so-called "DAS 1.0" solutions fundamentally solved the RF signal distribution over passive antennas to distribute the combined RF signal sources from multiple operators. The "DAS 2.0" active DAS solutions solved the shortcomings of the Passive DAS, namely short reach and PIM interference, by leveraging RF-to-optical conversion for longer transport. With the Open RAN (ORAN) radio construct and the use of virtualized baseband, the "DAS 3.0" solutions, which we refer to as "Multi-operator Distributed Radio Systems (DRS)," incorporate new digital technologies such as active antennas, ORAN radios, and virtualized baseband. As we move into

the world of "DAS 3.0", we recognize that it looks very different than the DAS systems of the 1990s. We recognize that the term "DAS" is becoming outdated, so in the future we will track multiple architectures for in-building wireless together.



Source: Mobile Experts

Figure 5. DAS Transitions

The expanding "DAS 3.0" capabilities – now possibly including virtualized baseband signal source – offer new indoor solution sets for different venue types. For instance, in some enterprise locations with Private LTE application as a primary use case, an in-building wireless solution that incorporates both baseband signal source and pre-selected multiband radios may be sufficient. Meanwhile, traditional Active DAS combined with operator signal source, either small cell or macro base station, may be required for public cellular service coverage indoors.

The traditional DAS systems will continue to play a prominent role in servicing high-density, large public venues like stadiums. Meanwhile, the multi-operator DRS systems have the potential to play an increasing role in mid-to-large size venues that require optimized indoor coverage and capacity solutions for specific indoor applications. For smaller venues simply looking to expand public cellular coverage indoors, boosters and small cell solutions may be sufficient. Meanwhile, small cell-driven Passive DAS may be cost-effective to handle low traffic requirements in mid-size venues. For very large public venues like stadiums, macro baseband fed Active DAS will likely dominate in the future for 5G sub-6GHz carriers.

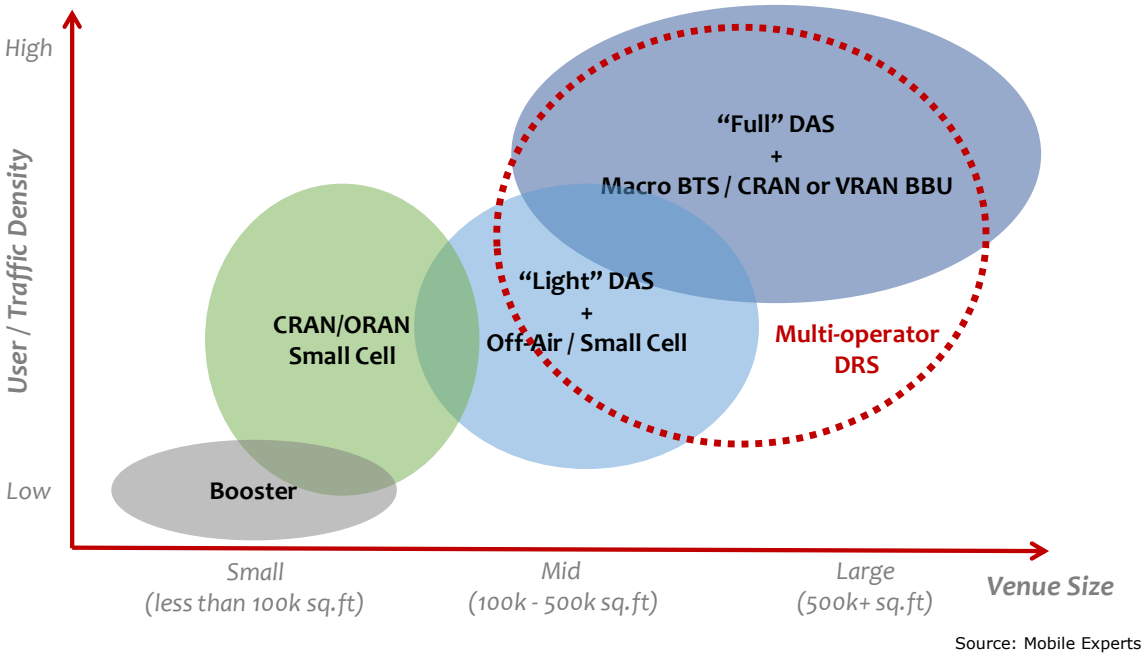
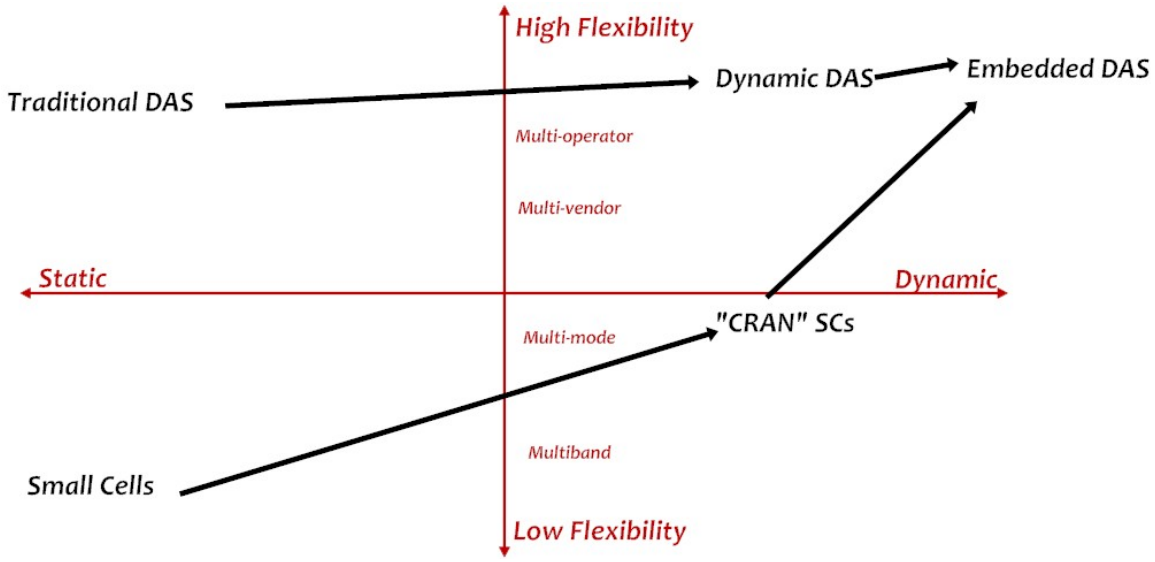


Figure 6. In-Building Wireless Solution Landscape

Ecosystem Evolution – Setting the Stage for Bringing 5G Indoors

We have been talking about a convergence of small cell and DAS towards what we called "Embedded" DAS -- a single operating unit encompassing both DAS coverage and small cell signal source or capacity. This thesis arose from our thinking that this type of solution can simplify the complex business model associated with DAS projects, as illustrated in Figure 2. As the traditional DAS vendors look towards the enterprise market opportunities and bringing 5G indoors, they are expanding solution offerings beyond "coverage" DAS solutions. New solutions include virtualized baseband and multiband radios supporting new spectrum bands including CBRS, C-band, and the millimeter wave spectrum.



Source: Mobile Experts

Figure 7. Evolution of DAS and Small Cell into "Embedded" DAS

We are seeing many DAS vendors expanding their solution portfolios beyond "RF" products including virtualized baseband and multiband radio solutions, such as JMA Wireless' XRAN and CellHub, Commscope's Era, CRAN indoor small cells, etc. The DAS suppliers have been acquiring "digital" small cell solutions over the past several years, including the Commscope acquisition of Airvana, Corning acquisition of SpiderCloud, and JMA acquisition of PHAZR millimeter wave specialist. We expect other DAS vendors to partner with other small cell or radio vendors to piece together combined digital and RF components making up the virtualized RAN stack. The 5G indoor requirements require combined "coverage" and "capacity" solutions across expanding spectrum bands, and the traditional DAS suppliers will need to acquire or partner in order to compete against much bigger tier 1 infrastructure vendors.

Enterprise DAS Challenges Remain But Improving

Mobile Experts has been talking about the need for market transition from Carrier DAS to Enterprise DAS for many years. This view was in anticipation of the slowdown in carrier-funded large projects that have historically driven the market. While we do see a rise in enterprise-funded projects, the challenges remain:

- The DAS model is too complicated. DAS must become easier to buy. Today, every project needs coordinated decisions from too many stakeholders, including the building owner, the city, a DAS supplier, a system integrator, and multiple mobile operators.

- Cost reduction is critical for the mainstream market. Major DAS project costs in the range of $1-2 per square foot are considered too high for many enterprises who are expecting the $0.50 per square foot range that they are used to in Wi-Fi deployments.
- Mobile operators must be eliminated from the decision loop to accelerate each project. This is the most critical factor in addressing the enterprise market. If a small enterprise project needs the approval of Verizon, AT&T, T-Mobile, and Sprint to proceed, the project will be delayed indefinitely due to lack of interest by the operators. Pre-approved products and streamlined procedures are needed.

Over the years, the mobile operators appear more amenable to Enterprise DAS projects willing to pay for the signal source. The operator programs like T-Mobile's Bring Your Own Coverage (BYOC), which tries to streamline procedure for enterprise indoor projects, offer signal source and backhaul. Over the past year, we have heard many instances where the operators are more likely to offer signal sources to indoor projects. While some of these operator programs are well-intentioned, a lengthy license retransmission approval process can be too long for many enterprises and system integrators. Enterprises are used to deploying Wi-Fi projects in 1-2 months, and lengthy 8-10 month DAS projects are too long for these smaller venue projects. Things are improving but not at the pace for many smaller enterprise projects.

Public Safety Drives Incremental Growth

The indoor public safety market has been a welcoming growth market segment for some DAS and repeater vendors. The migration of public safety systems, i.e., P25 and TETRA, to LTE broadband networks attributes to the growth in the indoor public safety market. The FirstNet ramp-up in the United States has provided a tailwind to the indoor public safety market.

Many DAS suppliers have introduced public safety DAS and repeater systems that meet regulatory requirements to address this growing market. Since public safety systems are mostly deployed separately from cellular DAS, due to more constraint requirements on survivability such as NEMA enclosure, and other monitoring aspects, this market is largely being addressed through high-power repeaters. Meanwhile, most DAS suppliers are adding support for LTE Band 14 for the FirstNet requirement across their Repeater and DAS product lines.

The public safety band support, specifically LTE Band 14 for FirstNet, is likely to increase over time simply as means to increase the market opportunity for the DAS vendors since supporting additional frequency bands is a basic part of the DAS business. While the public safety market is much smaller than the traditional cellular DAS market, it provides incremental revenue opportunity for DAS and repeater

suppliers who are looking to expand into adjacent markets. There is a growing number of competitors entering the space today as DAS and Repeater players see growing market opportunity for "FirstNet inspired" system upgrades. Traditional public safety players like Cobham is seeing increasing competition from other suppliers like Comba, ADRF, and others.

Regional Differences in In-Building Wireless

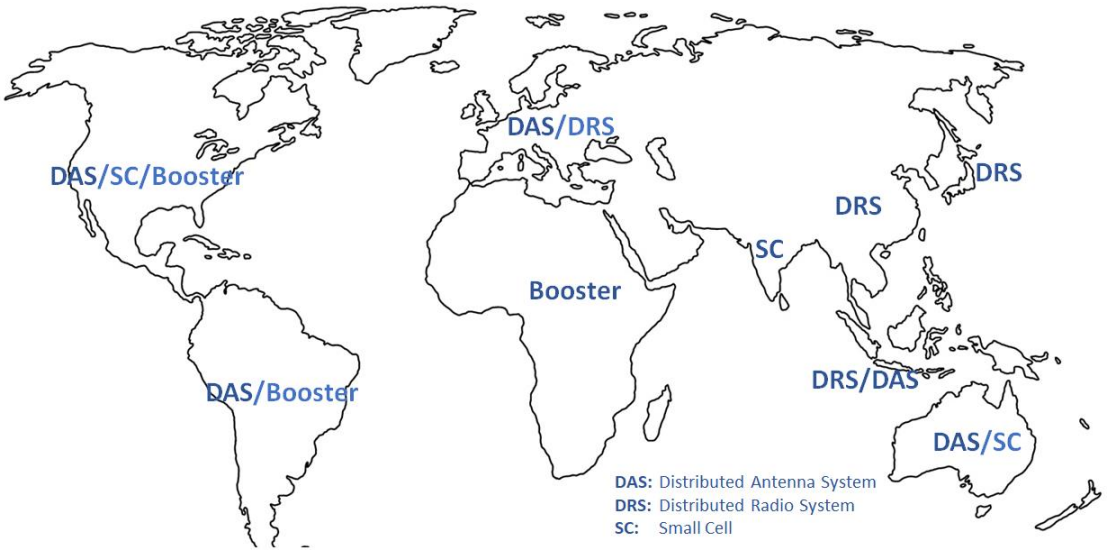
Not much has changed in terms of regional preferences for in-building wireless solutions and architectures. The difference is based on some key factors as highlighted below.

Economics and Mobile Adoption: A key factor in what in-building wireless solution gets adopted in a particular market depends on the overall macroeconomic condition in a region and whether or not an in-building wireless solution is needed. In developing markets where LTE and smartphone adoption is still far in the future, mobile traffic growth is more tepid. When mobile usage reaches a critical inflection point where almost everyone uses mobile devices for communication and heavy data usage, the need for broader coverage, even inside buildings, becomes clearer. Since high mobile usage and adoption is closely linked to GDP, developed countries and regions tend to use mobile devices a lot more than developing countries. In the developed regions, venue owners and enterprises look to multiple in-building solutions, including DAS, Small Cells, whatever else is available, including Wi-Fi, to help alleviate growing traffic demand. On the other side, poorer countries and regions primarily look to less-expensive Repeater or Booster solutions, which are easier to install and operate.

Industry Structure: Competitive markets with operators having similar market shares tend to drive towards DAS architectural choice. The reason is simply that multi-operator support becomes even more crucial in a market where operators have a similar share of subscribers. Mobile Experts believes that the USA market will eventually come down to roughly co-equal, three-operator market. We believe the "three operators" market structure will be maintained in the USA for a long time and will incentivize most venue owners and enterprises to support all three remaining operators. For these reasons, Mobile Experts expect the Active DAS market to remain strong and dominant in North America.

Carrier vs. Enterprise Ecosystem Maturity: The small cell-centric DRS solutions have been popular in markets where carriers are expected to fully "own" mobile infrastructure systems. Historically, mobile operators in China and Asia tend to fully address mobile coverage issues even in indoors. For this and other industry structural reasons, fiber access is cheap in Asia, and the mobile operators have taken full advantage of this. The operators in China and Asia have adopted the DRS

solutions in which centralized baseband pools are connected to in-building DRS networks with cheap fiber. In contrast, enterprises in North America and Europe tend to have a bigger 'say' in what in-building technology suits their overall IT needs. Moreover, operators in North America and Europe tend to focus only on key venues and have curtailed in-building wireless spending.



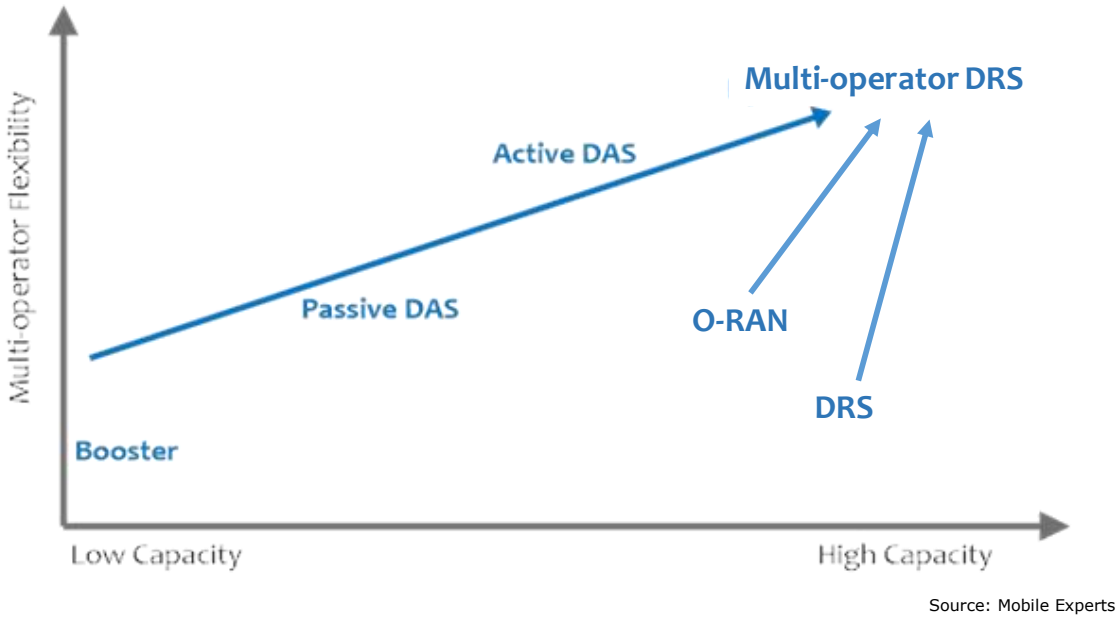
Source: Mobile Experts

Figure 8. In-building Wireless Solution Investment across Regions

With a diversity of carrier and enterprise investments in in-building projects, we see increasing use of hybrid solutions comprised of DAS, small cells, and boosters in variety of in-building projects in North America. While the bulk of in-building investments still occur in very large venues using DAS combined with Macro RRH's, we see rational utilization of different indoor solutions that offer optimal coverage and capacity solutions. In operator-dominant markets such as China and parts of Asia, DRS solution is becoming a natural evolution for operators to extend their CRAN architecture deeper into buildings. For developing regions where coverage is the primary goal, the use of Repeaters and Boosters will remain a viable option. In general, we see a general towards what we call "Multi-Operator DRS" solution in which digital baseband interface is extended out to active antenna units to handle high channel bandwidth across a multitude of mid-band channels.

3. TECHNOLOGY OVERVIEW

Mobile Experts has been speculating for years about a possible emergence of Embedded DAS, i.e., a DAS incorporating pre-integrated small cell signal source to ease deployment, to target small enterprises that are looking for a low-cost, easy-to-deploy system like Wi-Fi, for licensed cellular coverage indoors. While we have observed some efforts in this regard, we haven't seen one that truly delivers on this vision. We have heard from DAS suppliers that "embedding" small cells onto DAS is not trivial. Considering these challenges, we wonder, "what's next?"



Source: Mobile Experts

Figure 9. Evolutionary Paths of DAS

DAS Evolution

The evolutionary path of DAS has been about extending the reach of cellular signals indoors, first through coaxial cabling and passive antennas and later via fiber and active antennas.

Passive DAS

In the early days, DAS systems simply distributed an RF signal over coaxial cables. Passive DAS is an RF system with coaxial cables with passive antennas along the path to distribute RF signals within a building. For the multi-operator operation, multiple RF signal sources from the different operators are combined and distributed over coaxial cables. As a passive system, no coordination is needed with macro networks,

providing a simple integration for a neutral host operator – RF signal sources are simply connected an RF combiner in the DAS headend, and the "combined" RF signals are distributed out to remote radio nodes which amplify and transmit wirelessly via antennas connected to the remote nodes.

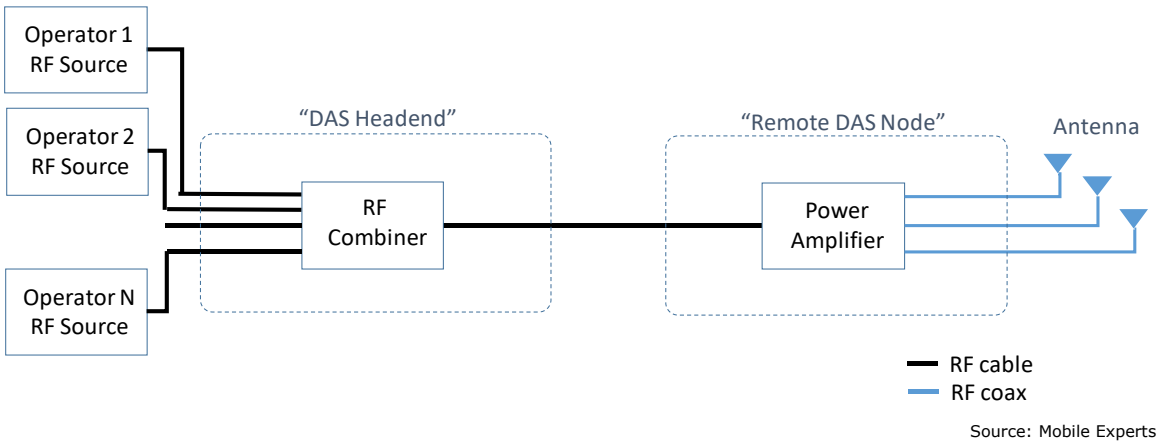


Figure 10. Passive DAS Functional Architecture

As operators added more and more frequency bands onto a system, the passive DAS began to buckle from passive intermodulation (PIM) interference, which essentially causes "noisy" distortion of desired signals. As requirements for DAS systems became more data-intensive and capacity-driven especially at very large venues like stadiums, a new architecture approach was needed to overcome the PIM interference and the problem of short reach between base station sources to passive antennas.

Active DAS

The shortcomings of Passive DAS, i.e., short reach and PIM interference, provided the motivation for Active DAS. In an Active DAS, a headend system effectively converts RF through IF down-conversion to an optical signal that is transported over fiber optic cable to a remote unit, which converts it back to RF, amplified, and transmitted via antennas. The RF-to-optical conversion provides better protection against PIM interference, and the optical transport provides a much longer reach between RF signal source and remote antenna units. In most DAS deployments in North America and Europe, Active DAS is prevalent.

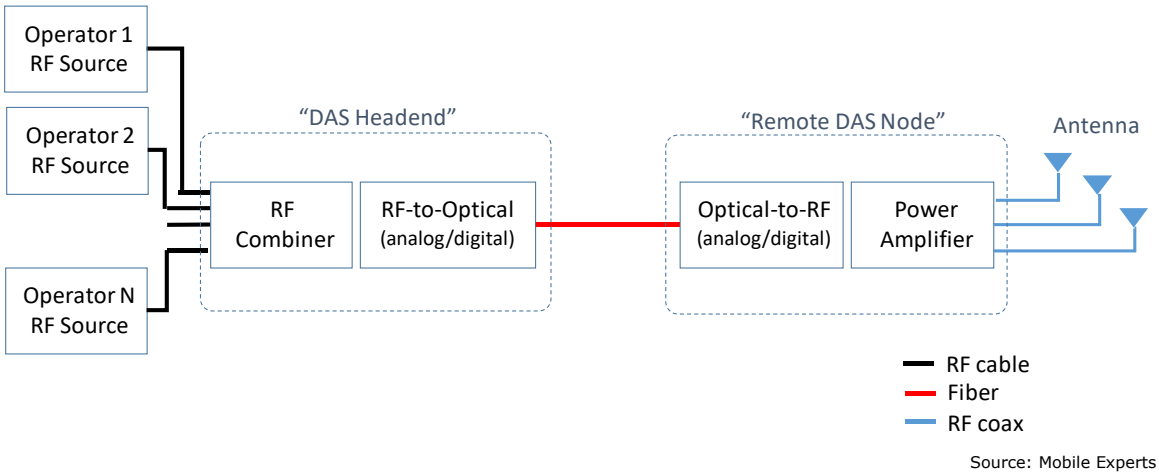
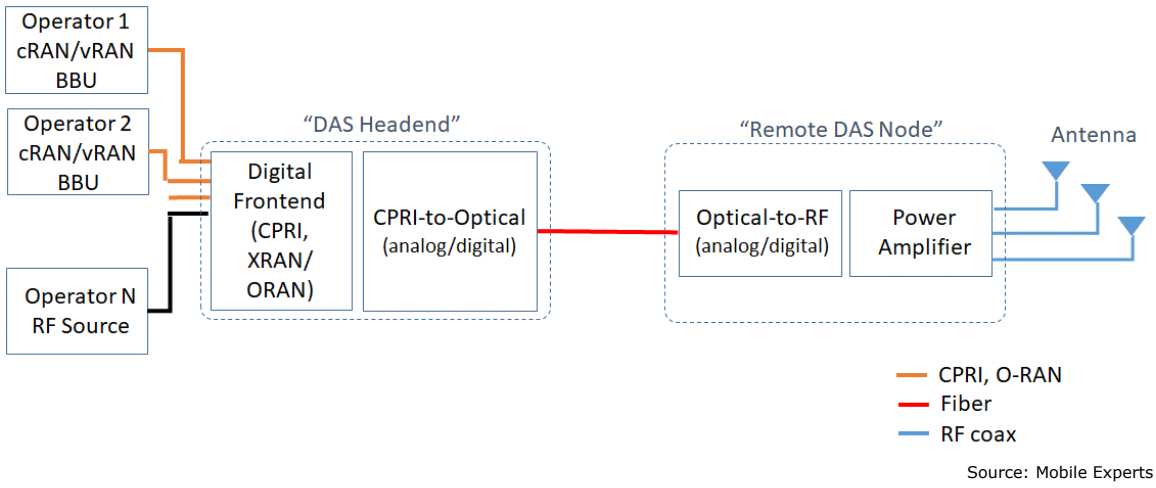


Figure 11. Active DAS Functional Architecture

Multi-operator Distributed Radio System (mDRS)

The conceptual Multi-operator DRS builds on the Active DAS architecture plus open virtualized RAN baseband unit (BBU) to different DAS sectors. Over the past two years, Mobile Experts have referred to this idea as "Embedded DAS." Multi-operator DRS (mDRS) is slightly different than the original "Embedded DAS" concept in that the open virtualized BBU would be considered a separate resource that can be on-premise or hosted at a remote "edge-compute" facility miles away, rather than "embedded" in a DAS headend.

A key tenet of the mDRS is that baseband resources can be scaled based on specific capacity requirements at a venue to optimize the use of baseband resources. For a large venue with dynamically changing capacity needs, mDRS can provide cost savings. For example, for a large hotel with adjacent convention center, where capacity need may change throughout the day, an mDRS can direct baseband capacity to the convention center area when that portion of the building is used, and then redirect the same pool of baseband resources to other areas of the venue as the traffic demand wanes. The "capacity routing" capability can be built into the DAS headend, as shown in the functional architecture diagram below.

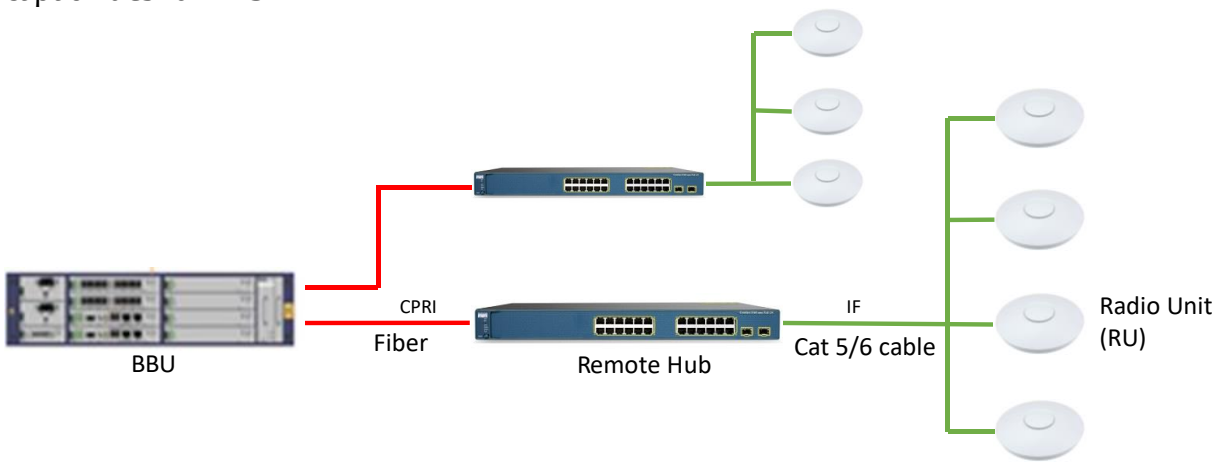


Source: Mobile Experts

Figure 12. Multi-operator DRS Functional Architecture

Distributed Radio System (DRS)

The Distributed Radio Systems (DRS) are Tier-1 RAN vendors' answer to indoor cellular challenges. Ericsson, Huawei, Nokia, and ZTE all have product offerings in this category: Ericsson Radio Dot, Huawei LampSite, Nokia AirScale Indoor Radio, and ZTE Qcell. They share the same architecture, as shown below. The DRS takes the centralized RAN architecture one step farther than other small cells. Instead of the remote radio head (RRH) feeding an antenna directly, the RRH (i.e., "Remote Hub" in the DRS architecture) leads to a series of distributed active antenna nodes (i.e., "remote radio units" or RRUs) to distribute RF signals deep within a building. While the architecture and functional aspects of DRS is similar to an Active DAS system, we generally view DRS as a "single-operator" system vs. "multi-operator" capabilities for DAS.



Source: Mobile Experts

Figure 13. DRS Architecture

As shown above, a DRS system consists of a baseband unit (BBU), a radio head unit hub (Remote Hub), and multiple remote radio units (RRUs). For example, in Ericsson Radio Dot parlance, the Remote Hub is called *Indoor Radio Unit,* and the RRUs are simply the *Radio Dots*. In Huawei LampSite parlance, the Remote Hub is noted as *RHUB,* and the RRUs are noted as *pRRUs*. In the DRS architecture, the same macro BBU can be used to serve the indoor small cell network. The Remote Hub is essentially an aggregation point for multiple RRUs dispersed throughout a venue to provide indoor network coverage. On the downlink, the Remote Hub transmits to all RRUs in a given single frequency network. On the uplink, it sums up and forwards the uplink traffic from multiple RRUs to the BBU. The RRUs convert intermediate frequency (IF) to RF and transmit over the air.

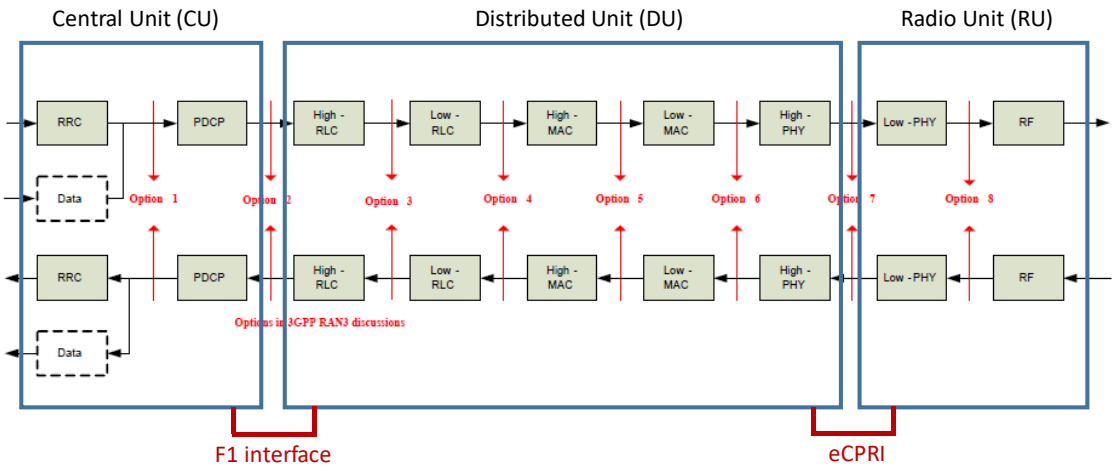
It should be noted that the IF connectivity over Cat 5/6 structured cabling between Remote Hub and RRUs is proprietary CPRI. Hence, you can't mix and match DRS network components between vendors. It should be noted that the Open RAN Alliance is trying to standardize the BBU/RRU interface.

Even though the DRS vendors have introduced the "multi-operator" feature whereby multiple operators can share a DRS system already deployed in a building or venue via optional "RF converter" box where RF signal can be "translated" into proprietary CPRI, we believe this will have a limited appeal in "neutral host" markets like North America where operators are less prone to sharing active network assets.

Open RAN (ORAN)

The Open RAN Alliance looks to "open" the Radio Access Network (RAN) by standardizing the interfaces between various components of RAN – namely the Central Unit (CU) handling higher layers of baseband processing for control signaling, the Distributed Unit (DU) handling lower layers of baseband processing for data handling, and the Radio Unit (RU) for remote radio head processing. While the efforts of ORAN is often talked about in the context of fostering Macro RAN vendor diversity and interoperability[4], ORAN small cells may find more uptake for the in-building wireless applications by enterprises and neutral host operators. For enterprise or neutral host operator networks, the high-performance demands on ORAN small cells may not be as great. The efforts of ORAN to "mix and match" different RAN components including baseband processing may afford scalable "coverage" and "capacity" solution that has alluded the DAS industry for small venue applications.

[4] Mobile Experts' *Open RAN 2019* report



Source: Mustala and Klein, Mobile Experts

Figure 14. ORAN Functional Components and Interfaces

CBRS over DAS

In last year's DAS report, we contemplated the use of LAA in DAS. While the idea in principle is feasible, in practice, there are many issues to resolve as identified previously, including congestion in the unlicensed band, Wi-Fi contention, coverage gaps between licensed and unlicensed radios, etc. Leveraging CBRS over DAS is less problematic. Running CBRS over DAS can potentially simplify and lower DAS costs in smaller projects. Instead of using high-count multiband DAS remotes to increase capacity indoors, operators can work with neutral host operators to support a few selected licensed anchor carriers for most of control signaling to manage quality of service while leveraging the common CBRS band for most of the data link layer. This way, the DAS remote can support a licensed carrier plus the CBRS band making the DAS design more simplified and potentially less costly.

5G Mid-Band (3-6 GHz) over DAS

Current DAS systems support sub-3GHz licensed carriers (as those are the limits of spectrum use in mobile networks today). As operators look to leverage the mid-band spectrum between 3-4 GHz, and possibly up to 6 GHz in the future, for 5G services, the requirement to support 5G over the mid-band will surely drive the market in the not too distant future. The question for DAS vendors, venue owners, and operators is, "what is the most economical platform to deploy that spectrum indoors?" Would it be a shared antenna distribution system (DAS) or operator-specific distributed small cell radios (DRAN)?

For "operator-dominant" markets like China where each operator will deploy own indoor systems, DRS solutions such as Huawei's LampSite, ZTE Qcell, Nokia Airscale Indoor, and Ericsson's Radio Dot provide a natural evolutionary path – i.e., replace existing sub-3GHz remote radio units with 3-4 GHz mid-band remote units.

Supporting LTE or 5G NR is simply a matter of directing a proper LTE/5G NR baseband digital signal. For a diverse "neutral host" market like North America, DAS arguably still provides economical and business benefits by leveraging same fiber/cabling and power infrastructure across multiple operators through shared DAS and remote units. With the possibility of carrying 100MHz of bandwidth per mid-band carrier, the fiber cabling and power infrastructure for DAS must be expandable to support higher transport and power requirements. With higher cable loss in the mid-band vs. sub-3 GHz, we believe more and more cabling infrastructure will move towards fiber-based.

Bringing 5G Millimeter Wave (24-40 GHz) Indoors

While it is reasonable to expect current DAS systems to be expandable to support higher frequency bands in the mid-band spectrum, it is highly unlikely to consider the millimeter wave band support on traditional DAS architecture with shared remotes handling multiple licensed carriers. As briefly mentioned in the *Preparing for 5G in Venues* section previously, some high-end venue applications may require extremely high throughput capacity (e.g., holographic imaging, AR/VR, etc.). To support such high-throughput applications, venue owners or operators may want to leverage the millimeter wave spectrum for the high-bandwidth channels. To overcome high-attenuation propagation of the millimeter wave bands, we expect these high-frequency, high-bandwidth spectrum bands will be deployed as integrated or RRH-based small cells with an integrated phased array for beamforming and beam-steering to specifically target user devices in the future. Thus, the millimeter wave frequency deployment will be a separate "layer" of hotspot small cells rather than shared remote units associated with typical DAS architectures in the near future.

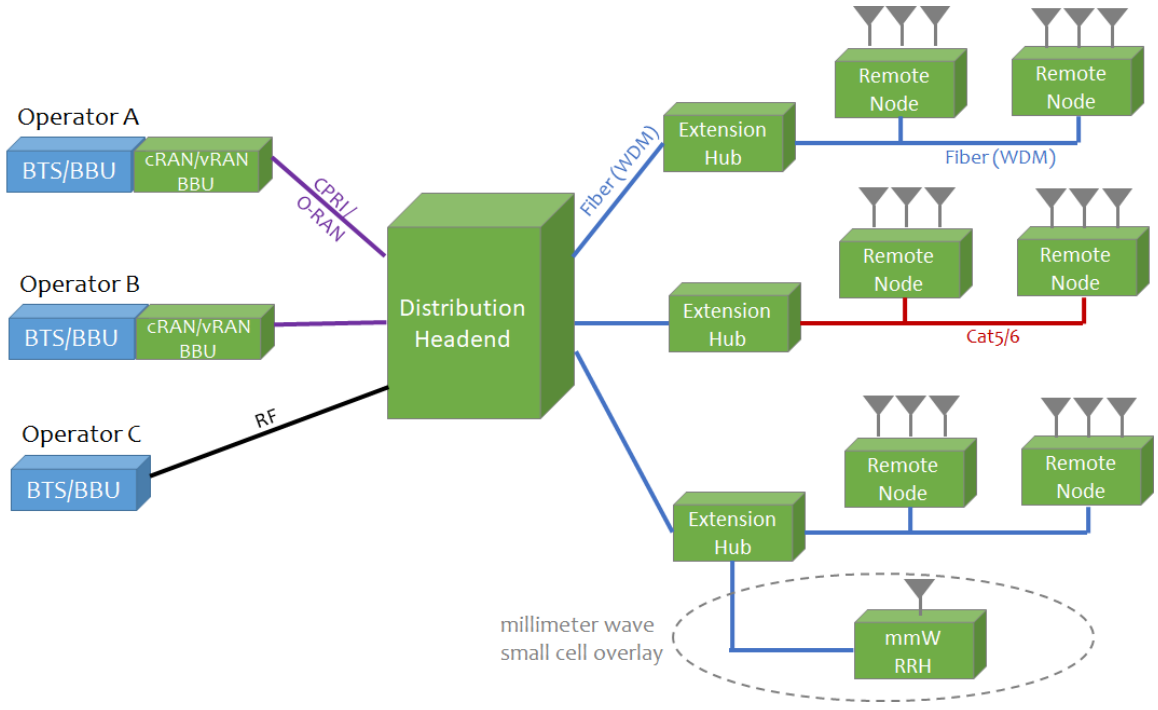
With the millimeter wave spectrum playing a prominent role in the 5G deployments in the USA until the C-band becomes available, it is inevitable that we will see some 5G millimeter wave indoor systems coming to key venues to tout the high-speed 5G services. In the near-term, we expect to see 5G millimeter integrated small cells or millimeter wave repeaters to be deployed in a few select venues, such as key public venues like stadiums and operator retail stores.

Future of In-Building Wireless and DAS: Digital, Fiber-Heavy, and Layered

The future of in-building wireless (IBW), especially at high-density venues such as stadiums, will continue to be served through DAS as neutral host business model is popular in North America. However, as the requirement to add higher mid-band and

millimeter wave spectrum for 5G, remote nodes will be increasingly fiber-based to overcome possible signal degradation due to cable loss. While some smaller enterprise-focused DAS may be sufficient with Cat 5/6 connections, the higher transport bandwidth requirement to serve a higher number of bands and wide-bandwidth carriers will drive fiber-based remotes. While smaller buildings may be okay with Cat-5/6 cabling in the near term, the transport between distribution (DAS) headend and remote radio units will increasingly require fiber and WDM to radio endpoints.

The high-performance features in LTE-Advanced like 4x4 MIMO, 256 QAM, Carrier Aggregation and 5G NR will drive higher RF performance in DAS. And, this, in turn, will require close coordination between DAS and the baseband scheduler to meet stricter timing requirements associated with LTE-Advanced and 5G especially in large venue projects where faraway remote radio units can cause time delay and poor overall performance. Good RF performance of an in-building wireless system will require a close calibration of DAS and LTE/5G BBU scheduler. For some DAS vendors targeting enterprise markets, having their own LTE/5G baseband source provides additional flexibility and differentiation by closely "tuning" DAS with the LTE/5G scheduler for optimal RF performance. Major DAS vendors have product development underway to create CRAN and VRAN baseband solutions that work with owned DAS solutions.



Source: Mobile Experts

Figure 15. Future In-Building/DAS will be increasingly digital and fiber-based

In addition to fiber-heavy cabling infrastructure, the future IBW DAS systems will increasingly require a digital fronthaul interface between signal source and the headend. The digital fronthaul interface between signal source and DAS headend (e.g, eCPRI, OpenRAN fronthaul) keeps the transport requirement reasonable and devoid of unnecessary power attenuation associated with using macro base station cabinet as a signal source. The digital fronthaul interface significantly reduces DAS headend space requirement by reducing a number of macro base station racks with a few CPRI interface cards.

Lastly, possible deployment of the millimeter wave spectrum in large venues will be overlaid as standalone small cells along with traditional DAS architecture for the sub-6GHz bands. The high-attenuation of millimeter wave will likely require unobtrusive signal path, and that may not fit well with traditional DAS remote installations (e.g., under seats, or on wall mount).

Overall, the future DAS architecture will be somewhat similar to today's architecture, but each IBW vendor will likely incorporate a home-grown CRAN or VRAN BBU for the signal source, and will be heavily fiber-based vs. other cabling alternatives. For some large venues with high-traffic application requirements, the future DAS will overlay with millimeter wave small cells targeting specific areas within venues. In all, the future in-building wireless infrastructure will resemble many traits found in operators' macro networks which are increasingly characterized by CRAN or VRAN BBU's closely connected to RRHs via fiber.

4. IN-BUILDING WIRELESS MARKET

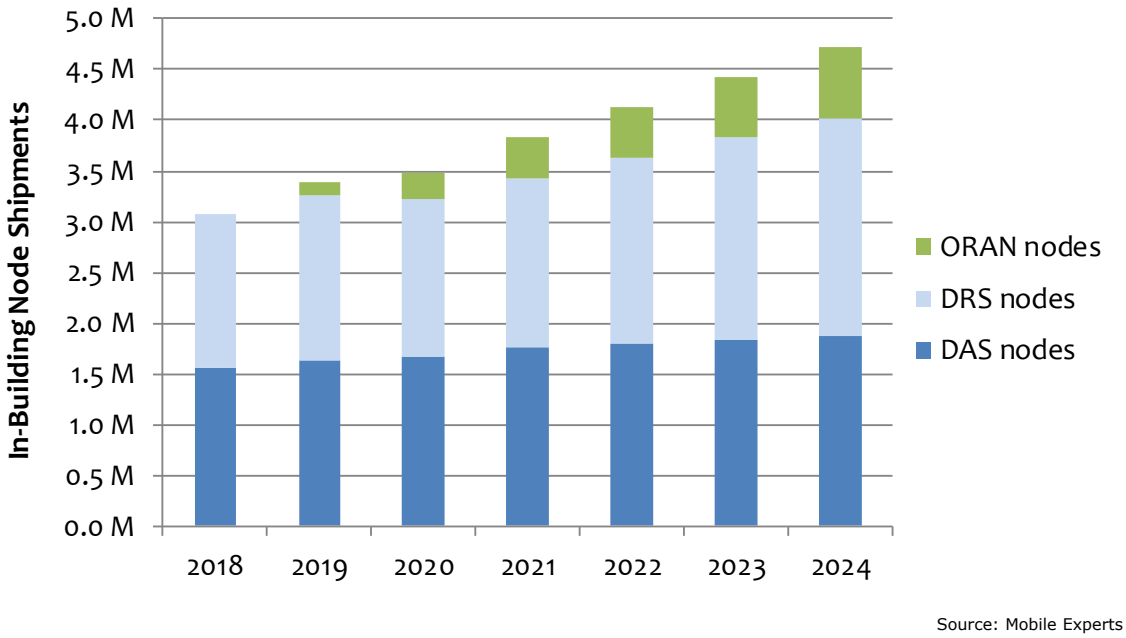
The in-building wireless market is undergoing a major change as operators transition to 5G with expanded spectrum choices from the mid-band to millimeter wave bands. While the traditional DAS market has slowed during this transition in the recent years as the volume of enterprise-funded DAS projects has not made up for the loss in carrier-funded projects, we see a bright future for the broader in-building wireless market, including DAS, Small Cells, Repeaters, etc.

(Note: while this report is mostly focused on the DAS market segment, we see broader changes in spectrum, technology, and business model choices for the indoor space in the years to come. For those reasons, this report is our last "DAS only" report, and we will broaden the scope of this research series to cover the "In-Building Wireless Networks" starting next year.)

In-Building Wireless Outlook – DAS, DRS, and ORAN

The DAS market has been synonymous with In-Building Wireless for many years as it was the primary tool by which operators and neutral host providers brought cellular coverage indoors at very large public venues. Some have asked 'how could the DAS market wane', as has been the case in recent years, when the mobile usage and traffic continues to grow. A quick answer to that is increasing technology and product choices and product-market fit. For operators, system integrators, and enterprises, the breath of solution offering continues to expand ranging from boosters, small cells, DAS, DRS, virtualized RAN, etc. While DAS remains the key segment of the in-building wireless market, there are numerous segments to consider ranging from boosters, CRAN/ORAN small cells, DAS, DRS, and others.

The DAS replacement cycle along with new technology choices such as ORAN and DRS and spectrum choices are bringing new options for both operators and enterprises to bring LTE and 5G services indoors. The operators have been expanding cellular coverage into large public venues like retail and entertainment complexes and airports through DAS, initially for multi-operator cellular coverage and increasingly for capacity with higher sectorization. With the preference for DRS over DAS in China, the DRS node shipments have been increasing faster. Also, we are seeing an increasing activity in ORAN as operators globally look to expand the RAN ecosystem through open standardization of RAN stack.



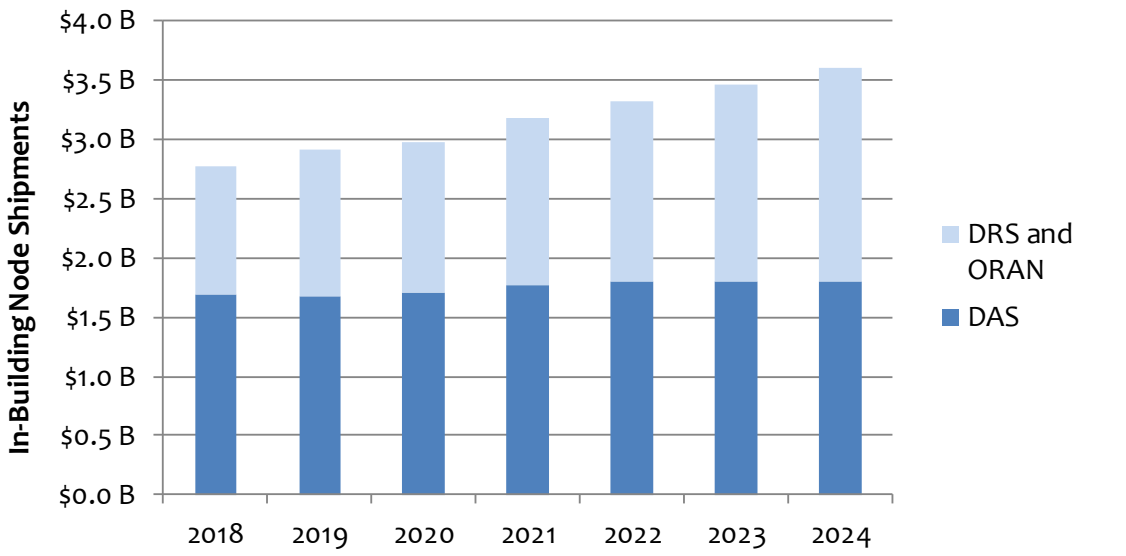
Source: Mobile Experts

Chart 2: In-Building Wireless Node Shipments, 2018-2024

As shown above, the number of DRS remote radio units are expected to grow faster than DAS antenna node shipments as operators in China especially, push for this architecture to push 5G signals indoors. We are in the early days of ORAN adoption, and it is unclear from which segment, DAS or DRS, that ORAN would take more share. Based on activities in China, we are currently forecasting ORAN indoor units to take more some share away from Tier-1 OEM's DRS deployments.

In-Building Wireless Equipment Revenue Outlook

In terms of equipment revenue, the DAS market will continue to make up for a larger share of the overall in-building wireless market with "neutral-host" deployments at very large venues in North America, Europe, and Latin America. Over time, the DRS and ORAN deployments will make up increasingly larger share of the market as it is already a preferred choice in China and will become competitive in other markets.



Source: Mobile Experts

Chart 3: In-Building Wireless Equipment Revenue, 2018-2024

5. INDOOR DAS MARKET

The DAS market is undergoing a major change as operators transition to 5G with expanded spectrum choices to the C-band (3-4 GHz) and millimeter wave (24-40 GHz) bands with much wider channel sizes. While the traditional DAS market has slowed during this transition in the recent years as the volume of enterprise-funded DAS projects has not made up for the loss in carrier-funded projects, we see signs of optimism from DAS replacement cycle under way at large venues.

Carrier and Enterprise DAS Segments

Mobile Experts has been talking about the "Carrier to Enterprise DAS" transition for the past few years. We have observed this market shift as the carriers limit indoor CAPEX spend only to key venues like stadiums, airports and other "high-value" targets. As a result, DAS suppliers have been refocusing their attention to adjacent markets in Enterprise and Public Safety markets for growth. While the multimillion-dollar projects at stadiums, airports, and other large public venues still happen from time to time, they are fewer in numbers nowadays.

While the market transition from Carrier DAS to Enterprise DAS is still on-going, the Carrier segment will not completely disappear. Many operators have owned DAS networks at key venues like stadiums for years, and they will upgrade those to handle additional mid-band and millimeter wave spectrum for 5G services. The DAS upgrades arising from the mid-band spectrum deployment will lay a foundation for the next phase of DAS growth especially in N. America. The Carrier DAS segment will remain a critical portion of the ongoing DAS market for years to come.

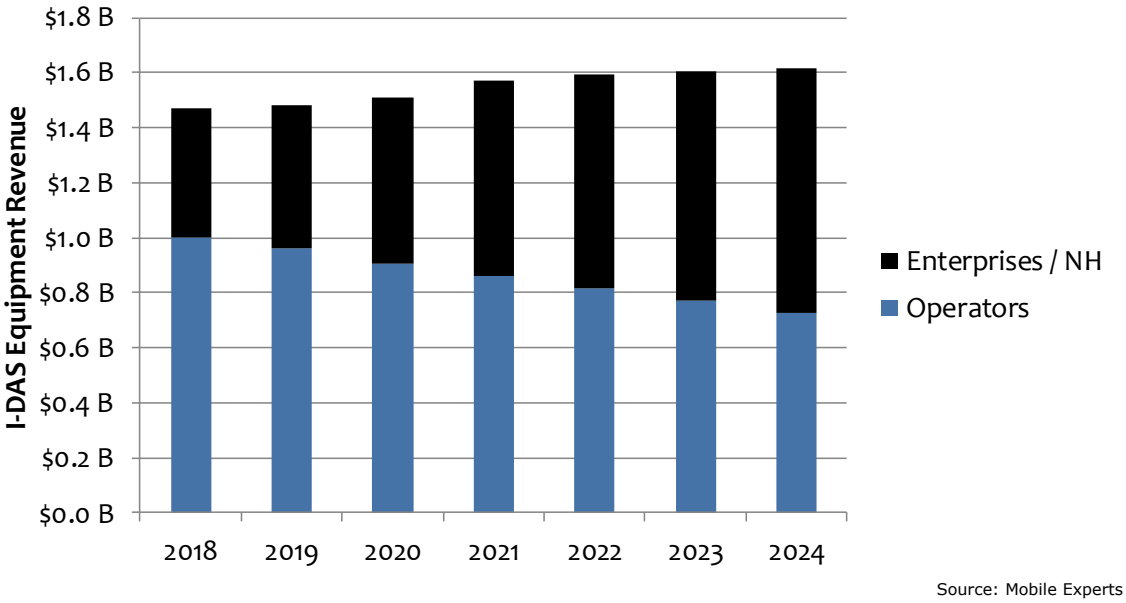


Chart 4: Carrier to Enterprise DAS Market Shift, 2018-2024

Large enterprises are taking a more proactive approach towards in-building wireless strategy. While enterprises have historically looked to mobile operators for cellular coverage indoors, this mindset is changing as mobile usage becomes more prevalent and some see Private LTE as another wireless layer for mission-critical enterprise applications in addition not Wi-Fi. For example, American Dream, a large retail and entertainment complex in East Rutherford, New Jersey, is looking to leverage not just the DAS system and enhance that along with CBRS network for traffic management operation at this very large complex next to the NFL stadium nearby.

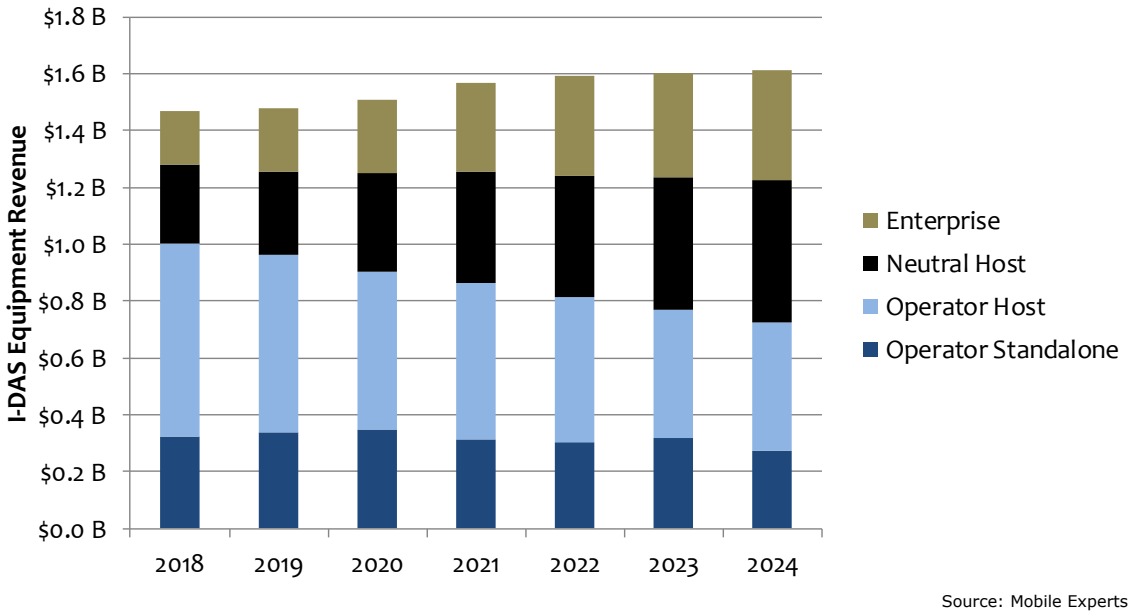
Mobile Experts estimates that the Enterprise portion, including neutral host provider portion, of the overall Indoor DAS market, to grow from over 30% in 2018 to about 55% in 2024. The flattish 1% CAGR growth in DAS equipment revenue is impacted by the pricing pressure that we observe in the DAS market. We are seeing a meaningful price reduction from some low-tier DAS vendors. We suspect that some of that pricing pressure may impact the growth opportunity for the major DAS players as well as system integrators and neutral-host providers will certainly use that trend as a leverage.

Indoor DAS Outlook

The DAS market transition from operator-funded Carrier DAS to direct- or neutral host-funded Enterprise DAS has been difficult for leading DAS players who have traditionally relied on operator-funded large projects for growth. While the market trend has been tough for many players, we are beginning to see upgrade-and-replacement cycles providing some growth for some of these players. Some of the

upgrade projects appear to be in anticipation of the LTE to 5G transition at large, but the continued traffic growth at key venues is likely the major culprit for the upgrades.

We believe that the mid-band (3.7-4.2 GHz) spectrum deployment inside major venues such as stadiums will largely rely on a proven DAS architecture. Adding the mid-band spectrum between 3-6 GHz will look very much like adding another class of remote units that can broadcast combined RF with multi-operator, multi-technology signals for the mid-band. We forecast that this mid-band spectrum deployment will earnestly begin in 2021 providing an uplift in major DAS upgrades at major venues.[5] For enterprise-driven smaller-venue segments, we believe other in-building wireless alternatives and hybrid solutions (e.g., Passive DAS with small cell as a signal source, active boosters , and standalone enterprise small cells) will be adopted. The DAS market segment will largely address the high-density, large public venues in the foreseeable future.



Source: Mobile Experts

Chart 5: Indoor DAS Forecast, by Ownership, 2018-2024

The overall DAS market is coming out of a trough as the replacement cycle is boosting the near-term prospect. Compared to our forecast last year, we are seeing an encouraging sign of growth in the traditional DAS segment in 2019. Even though the pricing pressure is more prominent this year, we expect the top end of the market will largely escape this negative trend in the near term. The Indoor DAS equipment market will largely be flat year over year at $1.48 billion in 2019 and grow

[5] The mid-band indoor deployment will largely depend on the C-band (3.7-4.2 GHz) auction. If private auction can be arranged with satellite players, the timing of the auction can be as early as mid-2020. If public auction becomes a path forward, then the timing of the auction will likely be early to mid-2021.

at 2% CAGR to $1.62 billion in 2024. The neutral host segment will represent the largest segment at the end of the forecast period as direct operator spend declines as they focus on only the top end of the public venues.

Indoor DAS Deployment by Vertical Industries

The level of indoor DAS investments varies by vertical segment and region. Large stadium projects, which spawned the DAS industry, remains the key market for continued investment by both the operators and venue owners. While the number of new projects is limited as most major venues have been built out, periodic upgrades and the build projects coinciding with major events like the Olympics continue to drive capital investments.

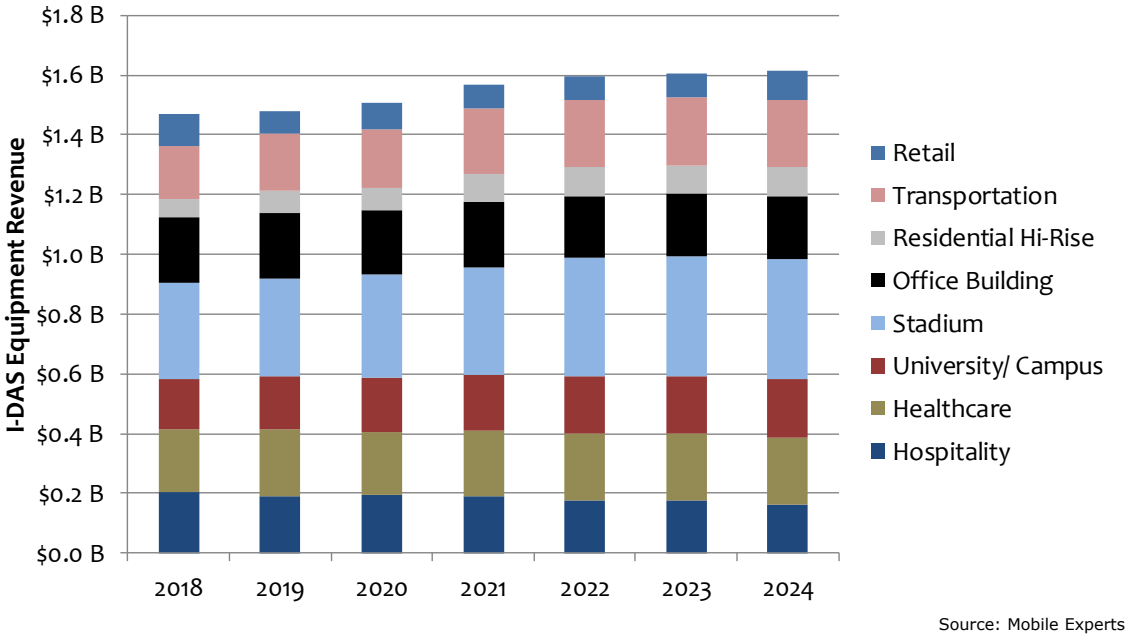
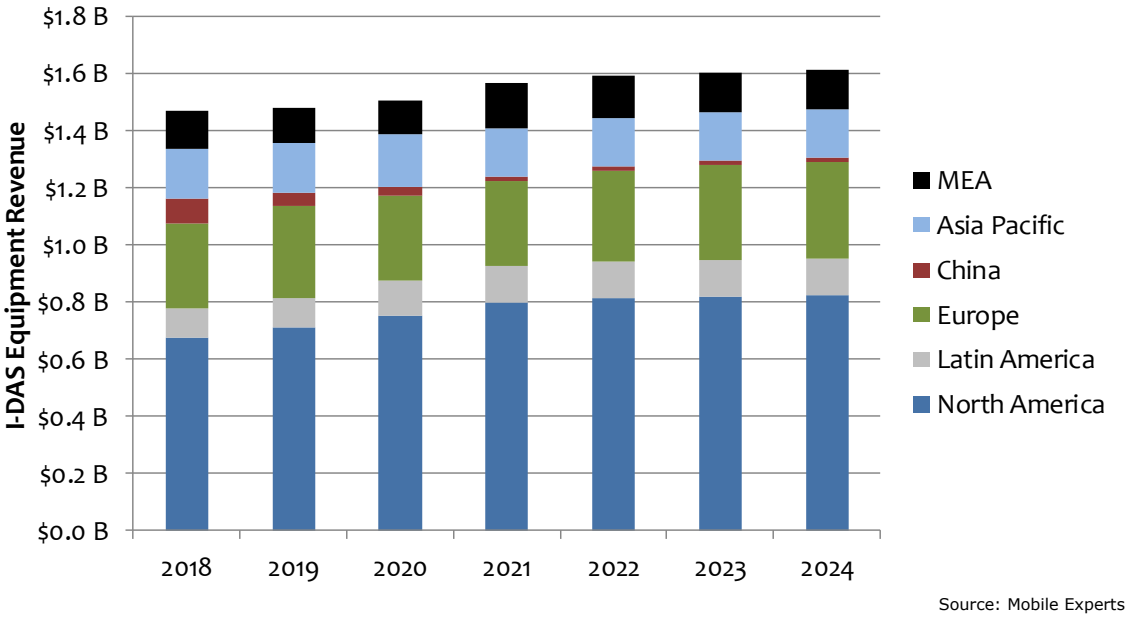


Chart 6: Indoor DAS Equipment Revenue, by Vertical Markets, 2018-2024

Over the past year, we have observed several DAS projects in the Transportation segment such as railways and tunnels. For example, London Underground and similar subway projects are providing the near term growth. Of course, the annual Super Bowl and similar sporting events always drive DAS infrastructure projects. The operators and venue owners are committed to making sure that mobile connectivity remains a priority for fans. Meanwhile, office buildings, corporate and university campuses, and high-rise luxury residential markets remain notable vertical segments where enterprises are making in-building wireless investments. For some smaller and IT-centric venues, we expect indoor alternatives like hybrid DAS/small cell and ORAN solutions to become competitive offering to that segment of the market over time.

Indoor DAS Deployment by Region

With high mobile consumption and traffic volume, North America remains the biggest market for DAS. It represents almost half of the entire indoor DAS market. North America, especially the United States, has a robust ecosystem of system integrators and neutral host providers covering myriad industry verticals and geographic regions. In addition to well-established neutral-host players including the tower companies and in-building infrastructure service providers like American Towers, Crown Castle, Boingo, ExteNet, and others, we have seen several new players entering the indoor "cellular as a service" market. Despite the trend of enterprises picking up the in-building wireless spend, much of that has been confined to smaller venues using less-expensive Passive DAS and booster solutions using small cell or "off-air" as signal source. While the upgrade cycle is providing a near-term boost to the North American DAS market, it is expected to be relatively flat over the long term as other alternatives like boosters and CRAN/ORAN small cells will drive the growth in addressing other segments. North America will continue to drive the overall DAS market.



Source: Mobile Experts

Chart 7: Indoor DAS Equipment Revenue, by Region, 2018-2024

Europe generally follow the North American market trend as the operators there face capital expenditure constraints in highly competitive markets. Indoor DAS deployments tend to require less capacity than those in the United States. The operators in Eastern European typically focus towards coverage in DAS investments thus high-value Active DAS deployments tend to be concentrated in top public venues. We expect the European market to remain relatively stable with gradual

growth coming from upgrades to mid-band deployments in the latter half of the forecast period.

Middle East and Africa (MEA) region continues to be lumpy with big construction projects driving DAS and other infrastructure investments. In most instances, these investment cycles are closely correlated to the oil market boom and bust cycles. After relatively active construction and infrastructure trends in 2017, the market activity has slowed down in the past couple of years.

Asia-Pacific region is a key market for mobile infrastructure and has been a strong base for DAS investments in the past, starting with Passive DAS then evolving to Active DAS systems for high-capacity venues. With LTE rollout, many carriers are starting to opt for RRH-based CRAN architecture. We have observed DRS solution ramp in some key markets like Indonesia where Chinese OEMs have network footprints. With promotion of DRS for in-building wireless solution, future DAS investments in this region is expected to be limited.

China is "all in" on DRS for in-building wireless with massive deployments of DRS products like Huawei's LampSite and ZTE Qcell. As most in-building wireless deployments are implemented for a single operator, the neutral-host "shared" aspect of DAS is not as important in this market. (Notably, in China the building owners do not put barriers up for mobile operators, so if an operator wants to mount a system in a building, there is no hassle.) The Chinese operators seem content to simply leverage CRAN-like DRS system indoors to extend the CRAN coverage and capacity indoors via DRS radio nodes. The China DAS market is almost non-existent.

Indoor DAS Forecast by Frequency Bands

Frequency band coverage continues to increase for large venue deployments as operators need to deploy additional licensed bands for capacity and speed increases. It is common to see a DAS remote node supporting up to 4 to 6 bands today and future remotes may support 7 to 9 bands in the future. While an enterprise-focused DAS system may purposely limit the number of frequency bands for cost savings (i.e., we have coined the term, "Light DAS," to describe this stripped-down configuration), but we believe the inherent benefits of multi-operator, multi-band, multi-technology nature of DAS will continue to expand the number of bands supported on remote nodes in general. For instance, a wideband remote antenna that can support all licensed bands under 3GHz, and up to 6GHz for the mid-band, would be a huge value. Whether the "wideband" capability comes in a single Remote Unit or a set of Remotes is left for specific vendor implementation. The need for extended frequency bands on DAS remotes will remain a key challenge going forward.

The frequency band support differs by region according to licensed spectrum assignments. For USA, it is common to see a remote unit supporting the major cellular bands including 700MHz, 850MHz, 1900MHz, and 2100MHz bands. For European and other regions, the major cellular bands including 900MHz, 1800MHz, 2100MHz, and 2600MHz are common. Moreover, the public safety bands from VHF, UHF to 700-800MHz bands are supported on public safety bi-directional amplifiers and repeaters.

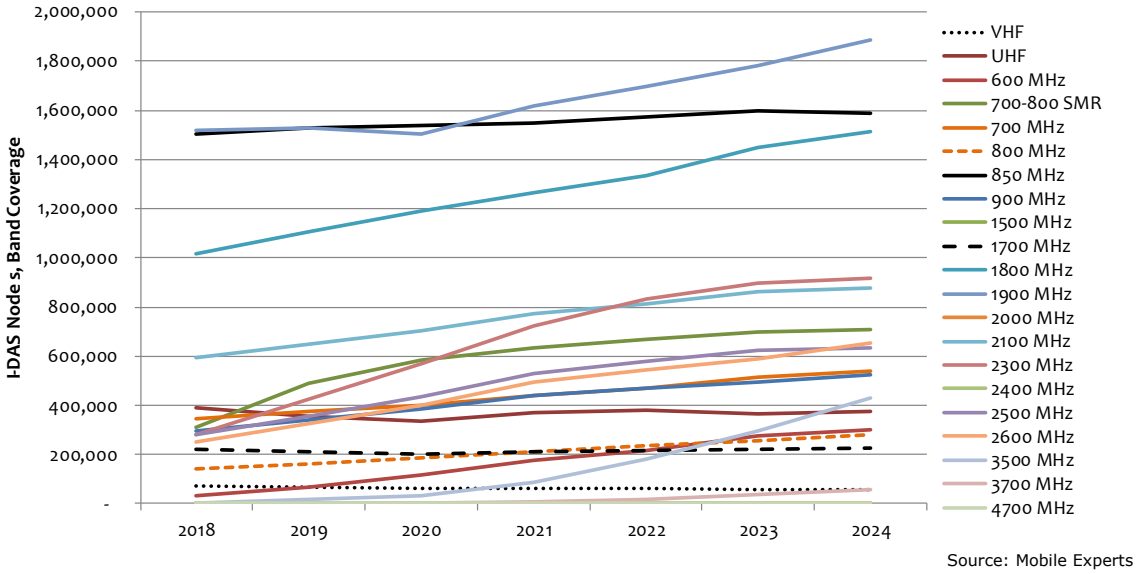


Chart 8: Indoor DAS Equipment Outlook, by Frequency Band Support, 2018-2024

Active vs. Passive DAS

The Passive to Active DAS transition has been going on for many years. The leading North American market has been driving this shift as higher RF performance required to accommodate LTE features like MIMO, low EVM, and high PAPR continue to push the system performance of DAS. Fiber deployment at large projects is commonplace now, and we expect this to be the norm as even higher 5G requirements to handle wider channel bandwidths will drive the market requirements. In some cases, like underground subway tunnels, using "leaky coax" cables to provide coverage in hard to reach places, akin to Passive DAS, is a more common practice. In fact, RF Systems has a good business providing this type of "leaky coax" cable solutions.

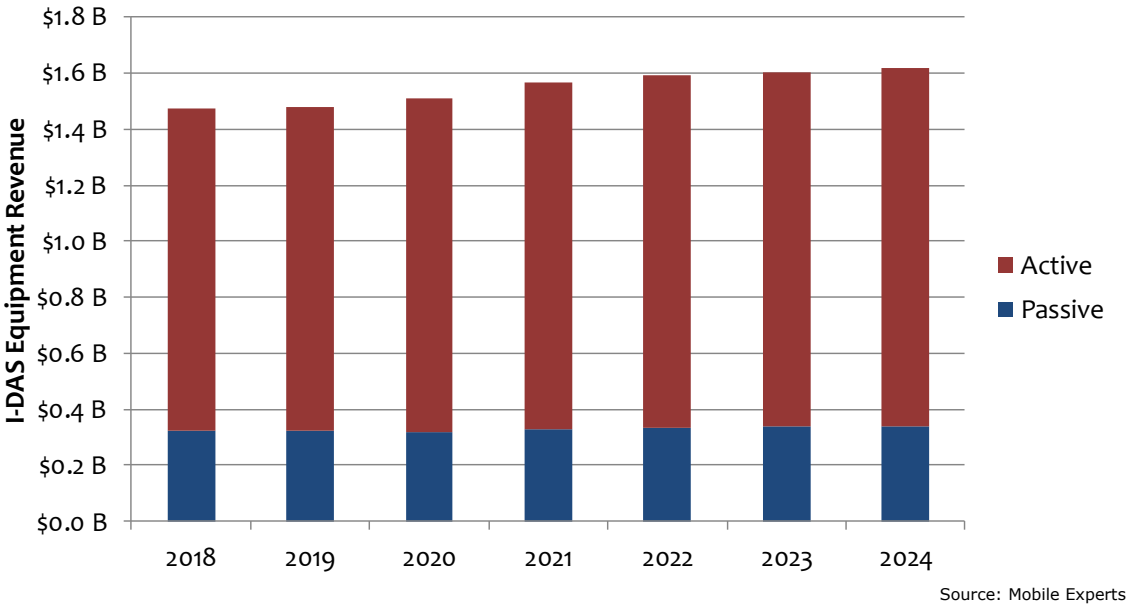


Chart 9: Indoor DAS Equipment Revenue, Active vs. Passive, 2018-2024

Both Active and Passive DAS markets will remain steady during the forecast period as they serve different needs in the marketplace. Coverage-driven indoor deployments will continue to leverage the inexpensive Passive DAS systems while Active DAS will largely serve high-density, large venues like stadiums.

Indoor DAS Forecast by Signal Source

In principle, DAS is a coverage solution, and it must be combined with a signal source to provide necessary capacity needed at a venue. For very large, high-density venues like sporting stadiums, a typical solution is macro base station cabinets to supply 50-200 sectors of throughput capacity. Meanwhile, a traditional macro cabinet type signal source is clearly wasteful and expensive in enterprise settings where capacity requirement is much less. Here, small cells are becoming a preferred signal source for these environments. For some high user-density venues, vendors are coming up with indoor small cells that offer significantly higher user capacity. The "off-air" will also remain a viable signal source for coverage-driven deployments in rural or suburban areas with low user density like in warehouses.

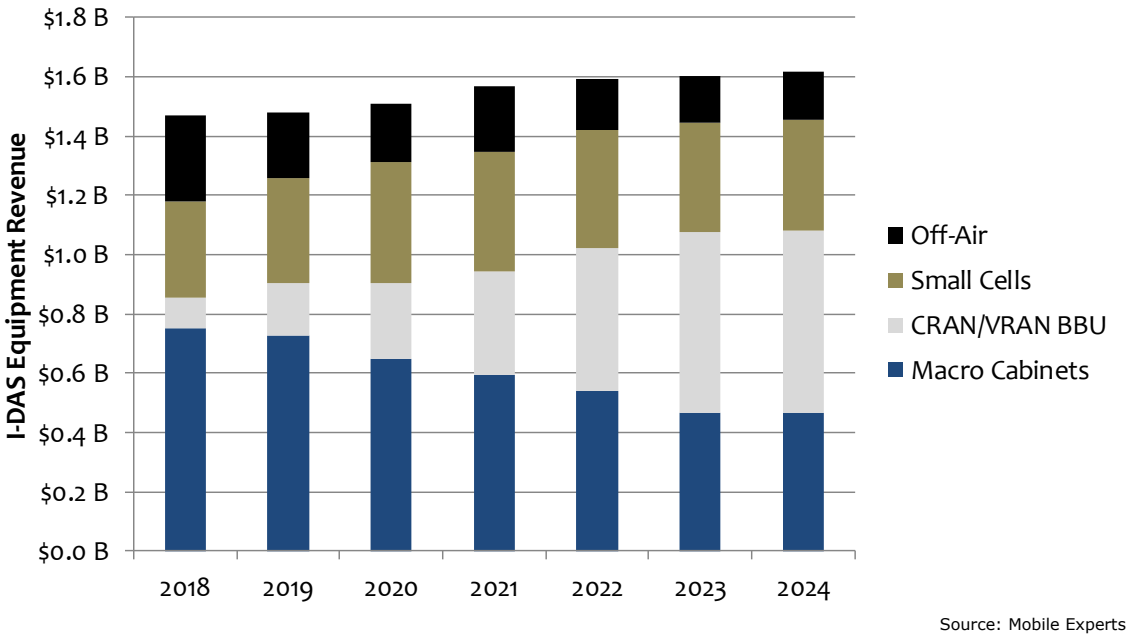


Chart 10: Indoor DAS Equipment Revenue, by Signal Source, 2018-2024

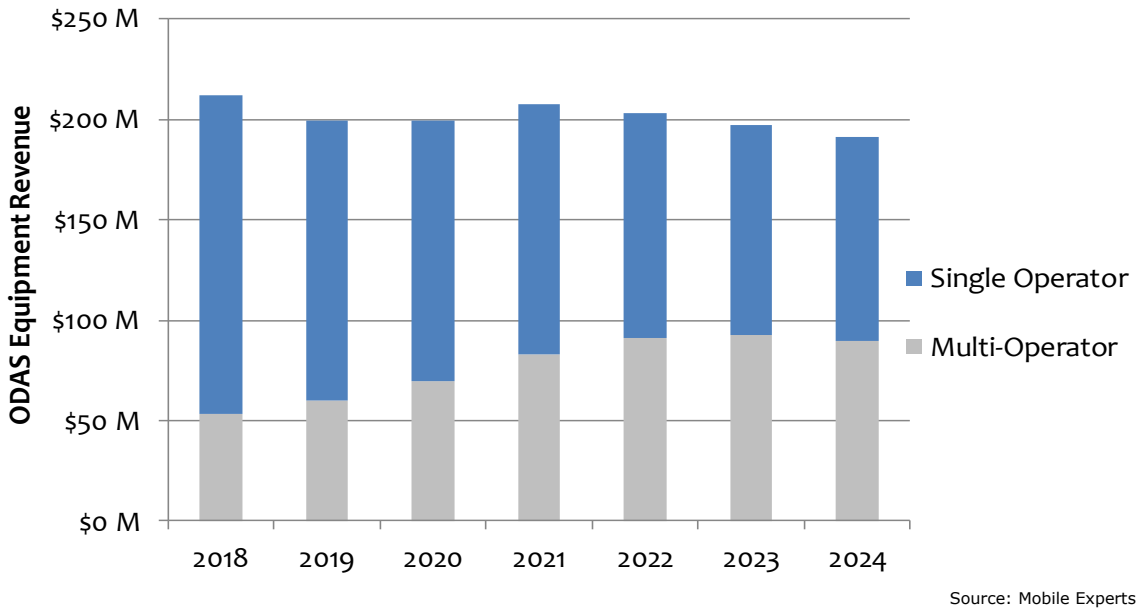
With a key focus to drive out costs in overall DAS projects, the CRAN or VRAN baseband units (BBU) are becoming popular alternatives in some DAS projects. As operators drive towards CRAN architecture overall, centralized BBU pools will be used to drive both indoor and outdoor systems. A direct CPRI or eCPRI connection between BBU and DAS further removes unnecessary costs associated with power attenuation of macro base station signals to DAS. As the RF and link capacity requirements between baseband and DAS continue to increase, a close integration between baseband and DAS and other coverage solutions will become more critical. Commscope's OneCell, Corning Spidercloud, and JMA's XRAN are some examples of DAS suppliers having own baseband solutions. Some tier 2 DAS suppliers are also partnering with virtualized BBU suppliers to develop ORAN solutions.

6. OUTDOOR DAS MARKET

Outdoor DAS market is very different than indoor DAS, but the delineation is harder to distinguish with many DAS applications that cover hybrid indoor and outdoor environments. As noted in our past reports, we define Outdoor DAS as multi-operator system utilizing high-power DAS remote antenna units (typically ranging from 10 to 40 watts) rather than vendor-specific remote radio heads for single-operator use.

Outdoor DAS Outlook

Mobile Experts has been observing a trend towards high-power outdoor small cells -- some operating at 40-80W composite power. With capacity constraints in urban markets, the mobile operators are increasingly looking towards outdoor RRHs or "mini macro" small cells instead of outdoor DAS to not only provide coverage but capacity as well to offload their macro layer. As a result, we expect a relatively flat market for Outdoor DAS.



Source: Mobile Experts

Chart 11: Outdoor DAS Forecast, Single vs. Multi-Operator, 2018-2024

As neutral host providers increase their presence in Outdoor DAS deployments for mobile operators, we expect the multi-operator deployment scenarios to increase as neutral host providers and mobile operators look to harness better economics through multi-tenancy and shared infrastructure. As the market transitions completely to the proprietary RRH units, we expect a continued growth for neutral host providers that participate in "small cell" or RRH deployments. This is not an

especially large growth area for the traditional DAS vendors with truly multi-operator products, however, as the Outdoor DAS market is only a small fraction of the overall DAS market.

Outdoor DAS Deployment by Region

North America dominates the Outdoor DAS market as the regulatory environment favors the neutral host DAS business model. In United States, each state or province maintains a list of registered Competitive Local Exchange Carriers (CLECs). A CLEC, by law, has the right to install telecom equipment on the public utility poles within that state. Since local municipalities control ordinances related to telecom installation within their jurisdictions, they take active roles in the approval process over matters such as the aesthetic appearance of equipment mounted on utility poles. As a result, there are thousands of municipalities in dozens of states and provinces, all of which have unique combinations of legal requirements for siting. Due to large numbers of different stakeholders ranging from CLECs and municipalities, mobile operators sometimes work with these neutral host infrastructure companies such as Crown Castle, ExteNet, Mobilitie, and others.

Even though the FCC has passed rules to streamline and expedite small cell deployments[6], the local municipalities ultimately enact local legislation on "right of way" code compliance. The FCC proposal for streamlining site acquisition has helped to inform the municipalities and the industry to expedite the process. For example, the public-private partnership announcements from major mobile operators and cities are indications that productive discussions are being had between the stakeholders.

[6] FCC released proposed wireless infrastructure siting guidelines establishing two new "shot clocks" for co-location on pre-existring structure and new builds (Sep. 2018)

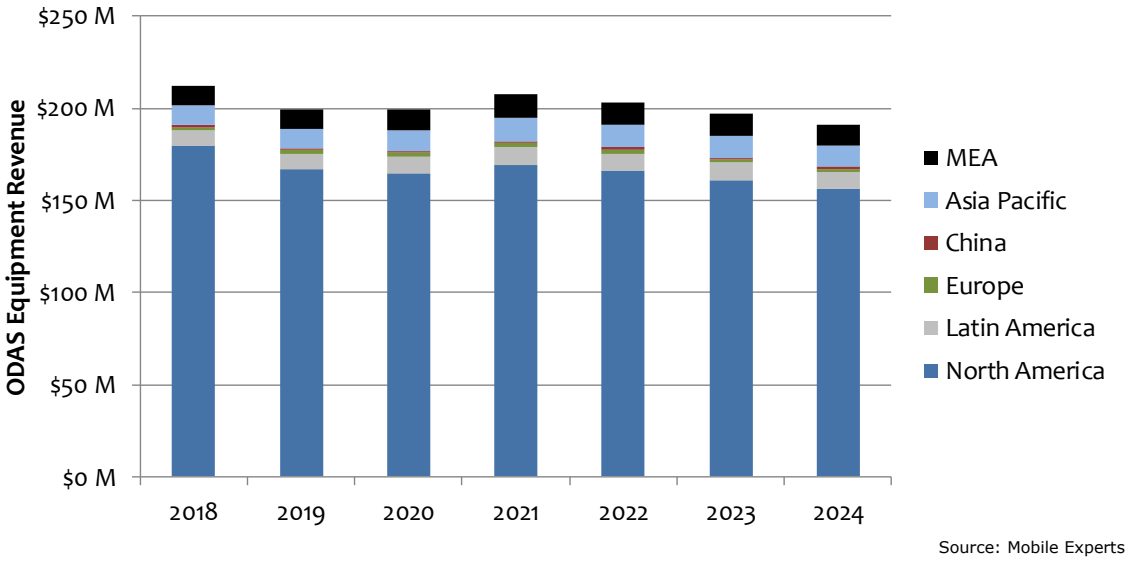


Chart 12: Outdoor DAS Equipment Outlook by Region, 2018-2024

The shared infrastructure model is well established and understood in the USA. The overwhelming dominance of North American market of the overall Outdoor DAS market comes down to the fact that DAS is a product solution to overcome the regulatory headache and to save time for the mobile operators. The neutral host trend that DAS represents will continue especially in the United States. In other regions, the mobile operators may be able to simply deploy a RRH unit, without using a local DAS host, to bypass regulatory issues.

Outdoor DAS Deployment by Ownership

With a historical trend of building a broad outdoor coverage and capacity for mobility services, the mobile operators continue to prefer ownership of key radio infrastructure assets. This ownership preference has diminished a "neutral host" business model for the Outdoor DAS market. However, Mobile Experts believes that the neutral host providers will continue to play a key role in some markets such as in the United States where they have siting rights and existing neutral host deployments to provide cost savings in a shared infrastructure model. For hybrid indoor and outdoor campus deployments, enterprises will also deploy high-power Outdoor DAS remotes to provide seamless coverage for Public Safety as well as increasing number of operator licensed carriers extending into the mid-band for 5G services.

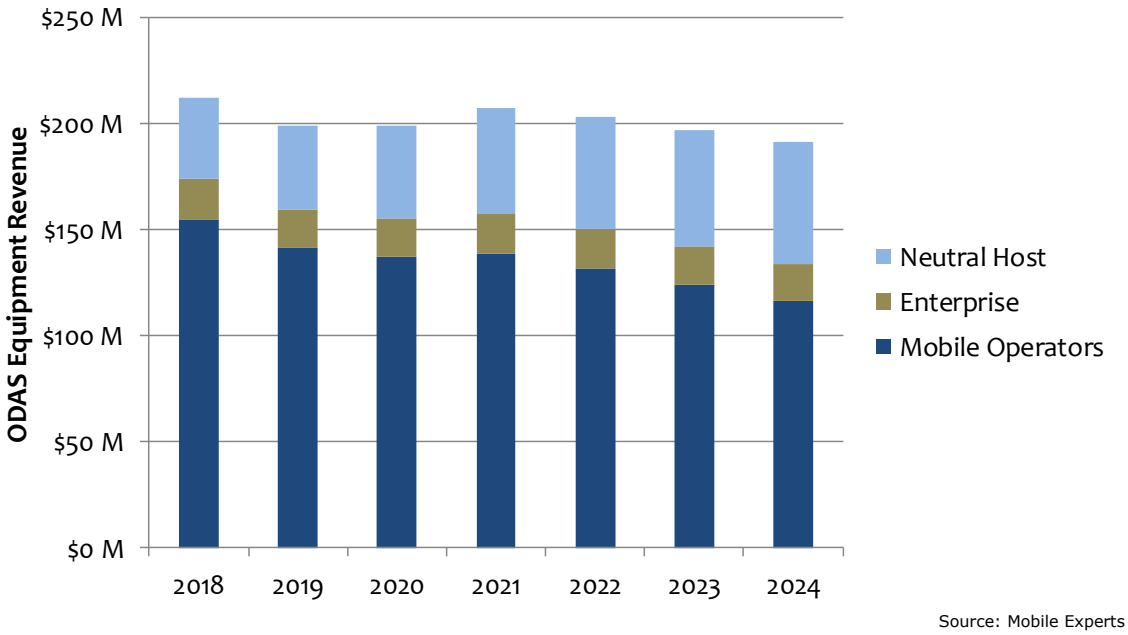
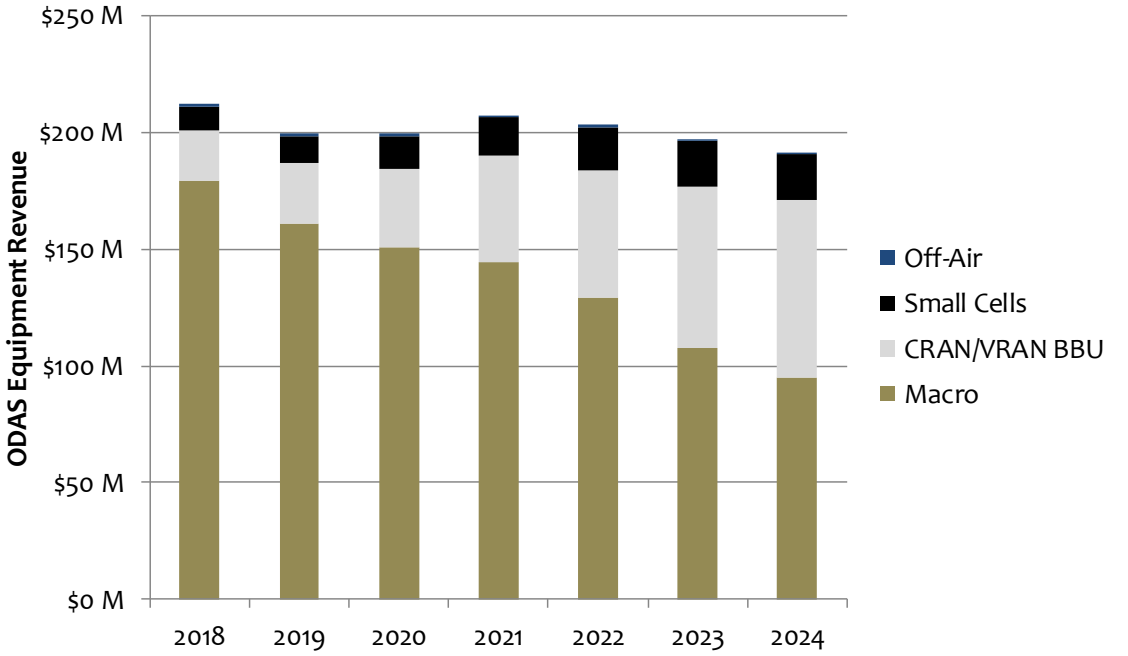


Chart 13: Outdoor DAS Equipment Outlook, by Ownership Model, 2018-2024

Outdoor DAS Forecast by Signal Source

As some mobile operators adopt CRAN architecture, it is more likely that centralized or virtualized baseband pools at a distributed metro data centers will drive a set of Outdoor DAS nodes. For some, high-power "small cells" with high capacity that can replace yesterday's macro base station will also drive some Outdoor DAS systems that do not have high capacity requirements such as suburban areas. In general, CRAN and VRAN baseband resources, along with some high-capacity "small cells" will drive Outdoor DAS systems over time.

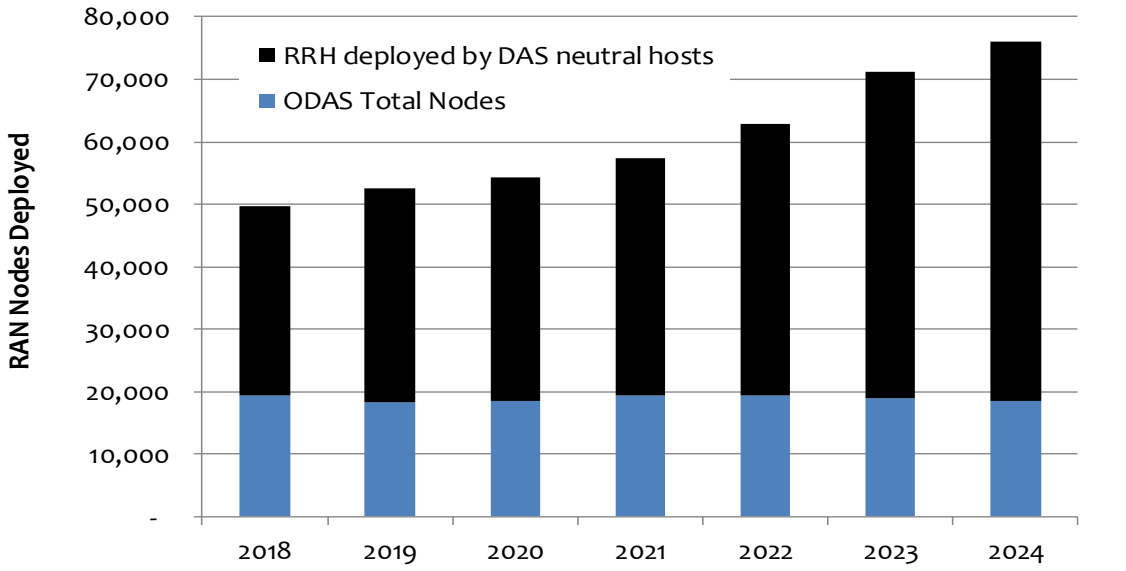


Source: Mobile Experts

Chart 14: Outdoor DAS Equipment Outlook, by Signal Source Type, 2018-2024

Outdoor RRH and Outdoor DAS Deployment Forecast

For blanket 3G or 4G coverage, the DAS integrators and neutral hosts usually deploy RRHs supplied directly from major OEM vendors. Because many Outdoor DAS installations service only one operator, the RRH implementation can be sensible in those cases, and there is no reason to deploy a truly shared DAS equipment. Mobile Experts does not track these RRH shipments as a part of the DAS equipment market, but as a reference, the following chart shows an estimated impact of RRH units deployed by DAS neutral host providers. Based on recent market indications of mobile operators self-servicing some small cell deployments and on-going difficulties of streamlining site acquisitions at many municipalities in the United States, we have reduced the number of RRH's being deployed by DAS neutral host providers. It should be noted that many neutral host providers including tower operators are reporting backlogs of radio deployments, but prolonged site acquisition processes are slowing down the velocity at which these RRH deployments can happen.

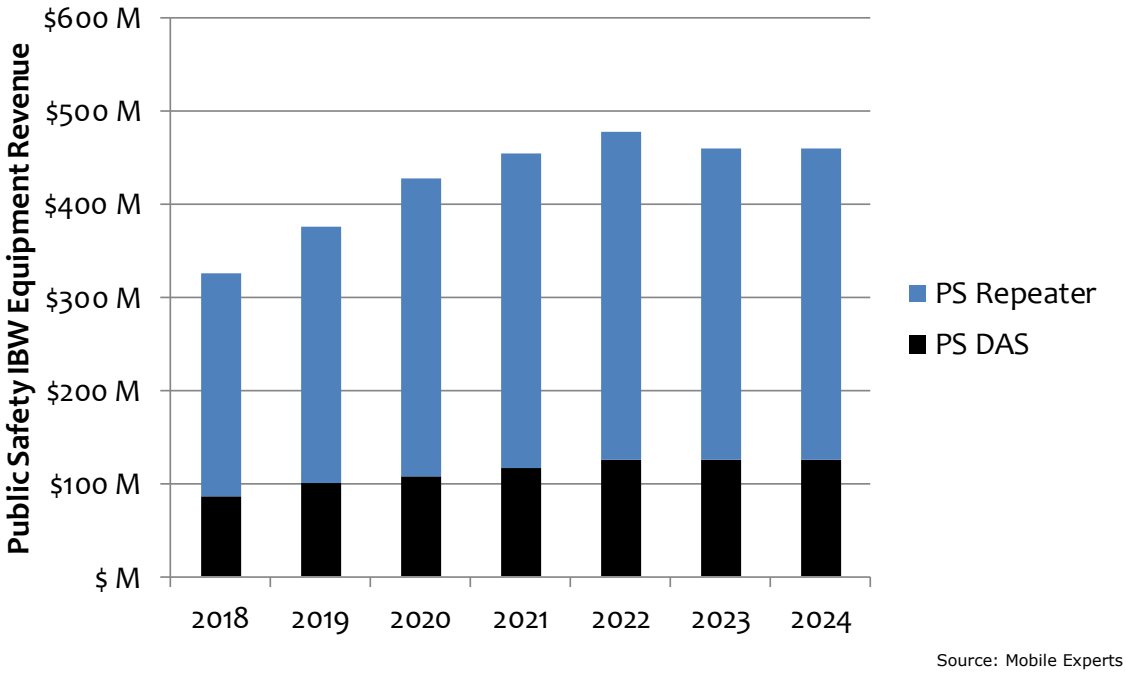


Source: Mobile Experts

Chart 15: Outlook for RRH and DAS Units Deployed Outdoors, 2018-2024

7. IN-BUILDING PUBLIC SAFETY MARKET

The Public Safety market is one of the fast-growing areas of the In-Building Wireless (IBW) market. The FirstNet network rollout in the USA has been a key driver in an increasing awareness and mandate to have the FirstNet applications and services to be available inside buildings for first responders. Current codes empower local and regional "agencies having jurisdiction" (AHJ's) to require public safety coverage in commercial buildings. According to the Safer Buildings Coalition, a not-for-profit organization promoting public safety communication inside buildings, over 40% of AHJ's surveyed currently enforce or plan to enforce the code.[7] With the FirstNet network deployment, we expect more AHJ's to enforce respective local codes, and this will drive further network investment of in-building public safety infrastructure. While the majority of incremental rise in public safety in-building wireless spend will come from the United States, a steady base of global investments towards LTE-based systems for public safety infrastructure will also drive in-building public safety investments elsewhere.



Source: Mobile Experts

Chart 16: Public Safety Repeater/BDA Outlook, 2018-2024

Mobile Experts forecasts the in-building public safety infrastructure including DAS and repeaters will grow at 6% CAGR from about $325M in 2018 to just above $460M in 2024. Public Safety DAS covering larger venues will consistently represent about 27% of the total Public Safety IBW spend during the forecast period.

[7] A Safer Coalitions Building presentation at DAS Congress 2018 event.

Public Safety Repeater/BDA Outlook

With significantly higher number of smaller buildings than larger ones, a single low-to-mid bi-directional amplifier (BDA) or repeater (less than 2W) can typically cover buildings less than 200-300K sq. feet. For smaller size buildings, a few hundred milliwatt BDA or repeater may be sufficient to provide the necessary coverage. While the number of BDA/repeater shipment will increase over time in the near term as the public safety systems transition towards LTE-based broadband infrastructure, the pricing pressure from new entrants and low-power BDAs costing a lot less will drive the overall public safety BDA/repeater market to put a downward pressure on the market growth. In the near term, the sheer volume of public safety BDA systems being put in place, especially in the USA, will drive the market growth.

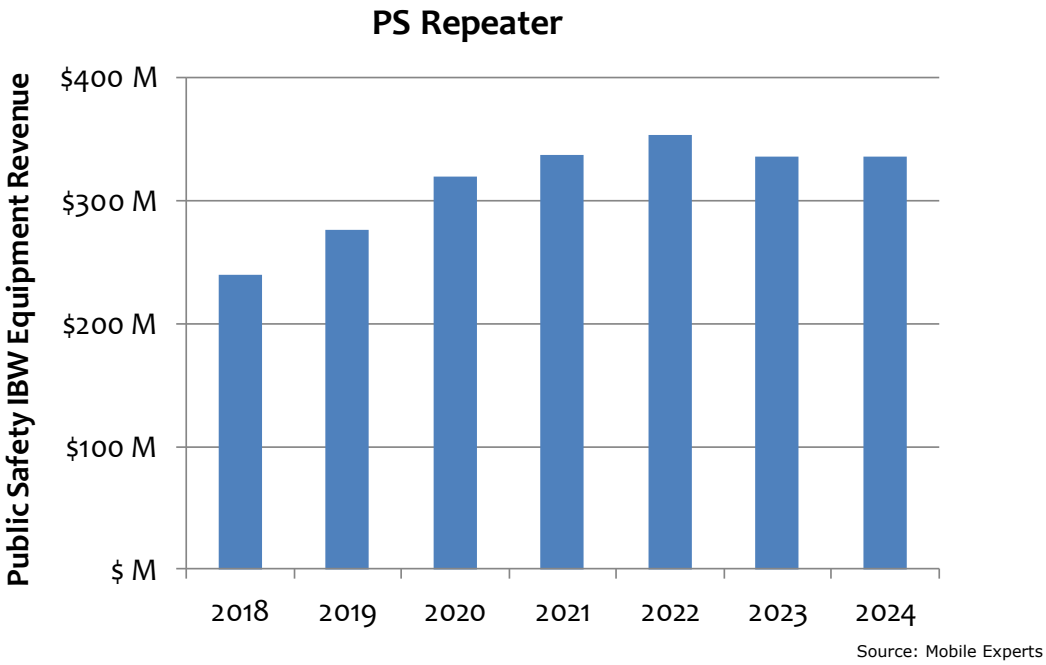


Chart 17: Public Safety Repeater/BDA Outlook, 2018-2024

Public Safety DAS Outlook

For larger venues or a campus environment with multiple buildings, DAS architecture may be needed to avoid potential RF interference issues arising from multiple BDA deployments. Specifically, the time delay distortion and donor antenna isolation problems in multiple BDA installations can cause problems with proper operation. In multiple BDA environments, coordinated benefits of DAS can eliminate those issues. Moreover fiber-based, Active DAS provides "clean" distribution of downlink power to remote units for ideal signal distribution across a large area. Targeting venues

larger than 500K square feet, we believe that the public safety DAS market targeting larger venues will grow steadily from less than $90M in 2018 to about $125M in 2024.

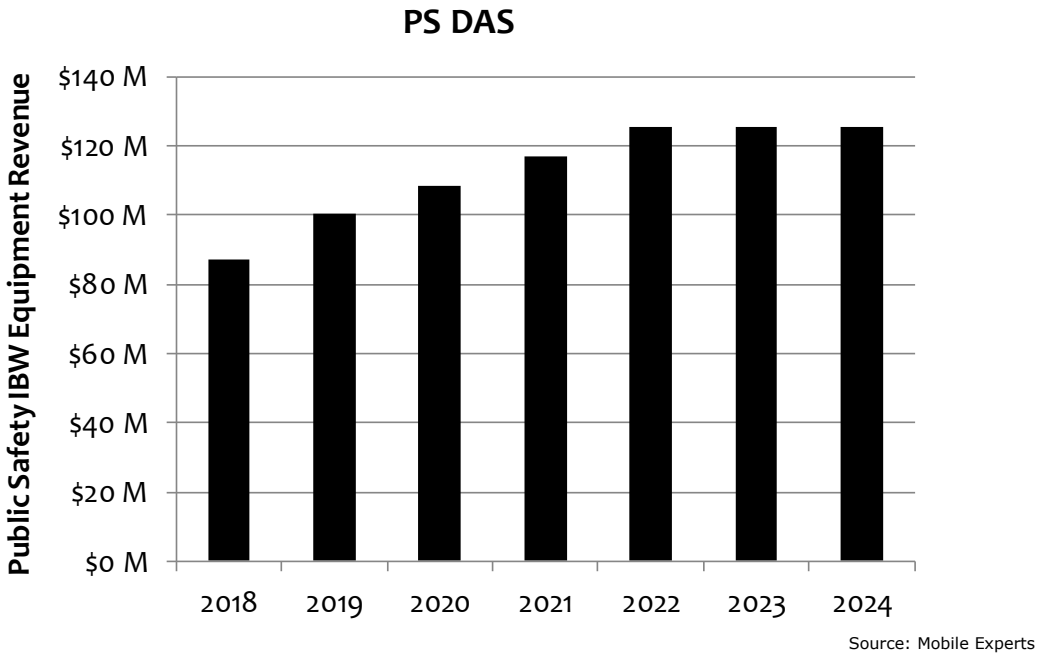
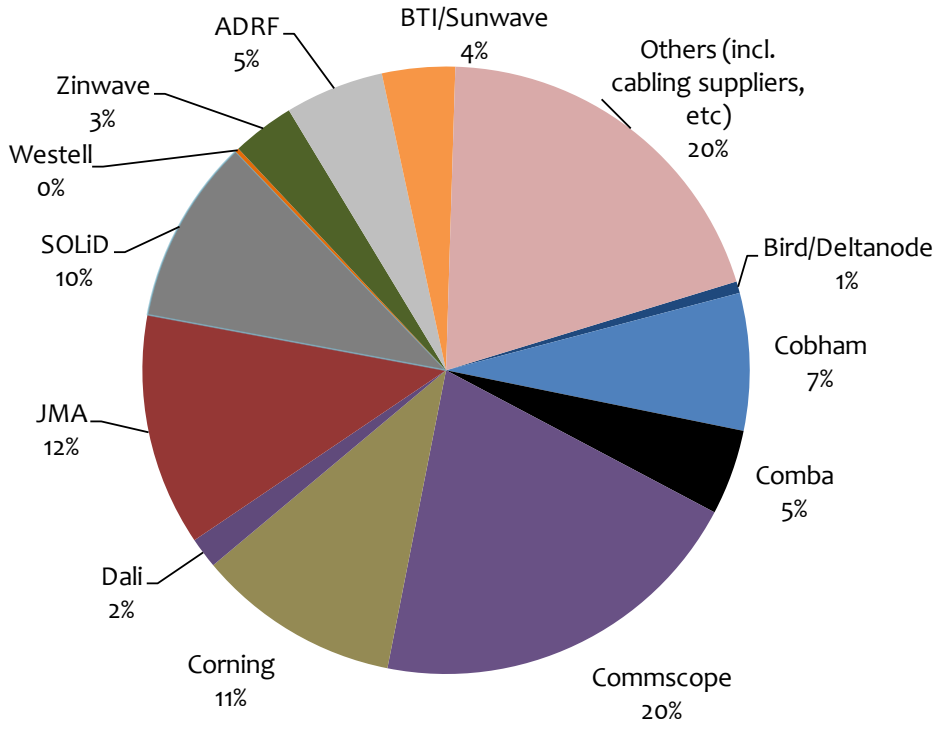


Chart 18: Public Safety DAS Outlook, 2018-2024

8. DAS EQUIPMENT MARKET SHARE

While the broader in-building wireless market is going through major changes with spectrum alternatives like CBRS and architectural choices ranging from DAS, small cells, DRS, and ORAN, the DAS market has been relatively stable. While the major DAS vendors, who have historically relied on large operator-driven projects, have been hurt in the recent years with fewer large projects to provide consistent sales, some are starting to see some uptick as upgrade projects are providing some uplift. Meanwhile, several minor players have been targeting the slowly growing enterprise segment and the public safety market for growth.

In this relatively stable environment, most players are maintaining their market share with the respective target market and regional focus. For example, the leading vendors in North America, namely Commscope, Corning, JMA, and SOLiD are maintaining their share. Cobham in the UK is largely focused on its strong base of customers in Europe with strong base in the public safety market. BTI Wireless as a subsidiary of Sunwave has been selling its new DAS gears into its base in SE Asia, Canada, and Australia, and has recently announced an 8-band, nano remote unit product that is similar in architecture to tier 1 OEM's DRS product.



Source: Mobile Experts

Chart 19: DAS Market Share by Revenue, 1H 2019

In talking with traditional DAS suppliers, everyone is aware of this shift in the in-building wireless market and is developing or partnering to develop flexible coverage and capacity solutions across multiple spectrum bands that operators are targeting including the 3-4 GHz mid-band and the millimeter wave spectrum.

9. COMPANY PROFILES

Advanced RF Technologies (ADRF)

ADRF has expanded as a supplier of in-building wireless solutions including DAS, repeaters, and active and passive components. The company has strong direct relationships with Verizon and Sprint and has expanded its product portfolio with a modular and compact ADXV product line. The company also has a broad product portfolio of public safety systems including digital repeaters covering the full breadth of public safety frequency bands across UHF, VHF, 700, and 800MHz. The company recently joined the Open RAN Alliance, perhaps pointing to its desire to incorporate open virtualized aspects in its 5G product roadmap.

American Tower Corp

American Tower is a major wireless infrastructure provider with a global presence in North America, Europe, South America, India, and Africa. The company operates about 150,000 wireless communication sites globally. In addition to its primary business of operating over 40,000 cell towers in the United States, the company has more than 1300 buildings under management and provides in-building DAS and small cell services mainly at large venues such as stadiums, malls, casino resorts, and office buildings. Moreover, the company manages hundreds of outdoor DAS nodes. With its core business of providing shared wireless infrastructure services, the company has strong relationships with all major operators and has a good growth prospect as a neutral host provider in the in-building space. The company has been active in CBRS Alliance as well.

Bird Technologies (Deltanode)

Bird Technologies, based in Ohio, acquired DeltaNode in 2013 to add to its repeater portfolio from TX RX Systems. Deltanode is a Swedish company that was spun out of SHL Group with extensive RF talent from Ericsson and Allgon. The company provides indoor and outdoor DAS equipment. While Bird's primary business is in test and measurement, Deltanode DAS products have resonated with customers in Canada, Europe, and Latin America, looking for custom designs. The company recently sold its TXRX repeater business to Indutrade, a Swedish holding company, in 2018.

BlackBox

Black Box is a system integrator/solution provider that provides comprehensive wireless solutions including DAS, small cells, CBRS, Wi-Fi for various enterprises ranging from healthcare, retail, finance, manufacturing, and hospitality. Black Box

acquired Inner Wireless in late 2012 and together they have focused intently on support of multimode DAS systems for enterprise applications.

Boingo

Boingo has transitioned from a Wi-Fi-centric neutral-host service provider mostly at airports to a major DAS player with over 35,000 DAS nodes in service. The company runs DAS, small cell, and Wi-Fi networks at airports, military bases, and other public venues. The company has expanded beyond its core airport venues to malls, hotels and military bases. With the company's recent acquisition of Elauwit Networks, Boingo is further expanding to multi-dwelling units in student housing and multifamily complexes. The long-term contracts with vertical segments allow the company to expand DAS, small cell, CBRS, and Wi-Fi networks into these markets.

BTI Wireless / Sunwave

Founded in 1999, BTI has grown from a power amplifier supplier to a supplier of in-building repeater, indoor and outdoor DAS systems, remote radio heads, and other products. BTI has major facilities in Southern California and Shenzen, China. As a subsidiary of Sunwave, a mid-size telecommunication equipment manufacturer, the combined company has a strong base of DAS installations in Canada, Australia, and Southeast Asia. The company recently announced CrossFire DAS system with low-power remote that can deliver up to 8 bands in a single access point fed by fiber or Cat-6A cable. The product is in commercial trials now.

Cobham Wireless

Cobham holds a strong market share in the European GSM-R market, with unique products that are tailored for high mobility coverage in tunnels and remote areas. Cobham routinely integrates public safety radio with digital repeaters, although the primary deployment model involves passive DAS systems due to cost preferences by European operators. Cobham also provides active DAS called idDAS for some high-density applications in stadiums, airports, and office buildings in Europe and other regions around the world. The company's in-building solutions, including repeaters and DAS systems, are mostly found in Europe with historical strength in the Public Safety segment with the company's core business in government and aerospace electronics.

Comba Telecom

Comba has been the main DAS supplier in China and other cost-sensitive markets. The company has recently focused on Latin America with several stadium deployments. The company has also worked together with top-tier OEMs in the deployment of radio heads for high-density indoor/outdoor applications. With the

Chinese operators' push in open RAN movement, the company has been active in ORAN small cell development. While the company's "5G Cloud small cell" products will serve a portion of in-building market in China and elsewhere, the company is focused on the Public Safety market in North America. The company's core antenna business provides a strong foundation with Chinese operators and international OEM channels upon which to expand its DAS and small cell businesses.

Commscope

Commscope is a leader in both indoor and outdoor DAS markets, with multi-operator products tailored for both market segments. Commscope has been expanding its indoor solution portfolio and intellectual property through acquisitions including TE Connectivity for digital DAS, Airvana for small cell, and Ruckus for Wi-Fi and CBRS radios. As one of the world's leading cable suppliers, Commscope can offer a full breadth of in-building wireless solutions with DAS equipment, antennas, and cabling to address the entire DAS deployment. In additional to its DAS offerings, the company also offers OneCell and Era, a digital DAS with active antennas.

Corning

Corning acquired fast-growing MobileAccess in 2011 and has continued the company's push into in-building DAS systems. Mobile Access had historically served enterprise customers, neutral hosts, and a few operators with in-building distribution systems. The company offers multiple product lines, targeted at 2G, 3G, and now 4G systems with MIMO support for LTE. The Corning ONE product offers dynamic capacity allocation with an all-fiber DAS network. With the Spidercloud acquisition, Corning now has an expanded indoor solution portfolio.

Crown Castle International

Crown Castle acquired NewPath Networks in September 2010 and quickly followed with the acquisition of market leader NextG Networks in April 2012. Through these acquisitions, the company became the market leader in Outdoor DAS systems. In recent years, the company has been buying up metro fiber assets with several billion-dollar acquisitions, including Sunesys, Lightower, and others. The company manages approximately 40,000 cellular towers, 60,000 route miles of fiber, and has 60,000 small cell/DAS nodes on air or under deployment.

Communication Technology Services (CTS)

Founded in 1990, Communication Technology Services is a major DAS and in-building wireless system integrator serving the United States. With about 600 employees, the company has a national presence and competes against fragmented regional players. The company has been involved in indoor and outdoor wireless deployments

including DAS, small cells, public safety, and Wi-Fi. In addition to installation services, the company engages in maintenance and monitoring services – really encompassing the full suite of installation to maintenance services.

Connectivity Wireless Solution

With headquarter in Atlanta, GA, Connectivity Wireless has been in business for about 10 years. The company has been involved in mid-size in-building wireless deployments primarily with DAS, but sees opportunities in CBRS, LAA, small cell, and managed Wi-Fi deployments. With the recent acquisition by a private equity firm, the company looks to expand its in-building wireless system integration business which is quite fragmented today.

Dali Wireless

Dali offers a distributed radio system with dynamic capacity allocation, essentially making "RF router." The company has been heavily focused on protection and monetization of its more than 300 patents, many of which relate to the use of CPRI and other IP formats to implement adaptive traffic capacity in DAS. The company has some interesting enterprise installations such as the Hilton in Los Angeles and the Dallas/Fort Worth Airport. The company is headquartered in Silicon Valley with research and development office in Vancouver, Canada. The company has recently partnered with KMW to implement open virtualized RAN solution, whereby KMW provides RU and the company provides CU/DU.

Ericsson

Ericsson is a tier 1 mobile infrastructure vendor whose Radio Dot product is similar to other DRS architecture solutions like Huawei's LampSite and ZTE's QCell. Last year, Ericsson introduced a "multi-operator" version of Radio Dot, which can effectively serve multiple operators through multiple remote units in a common enclosure, with electrically separate Cat 6 cables, or sharing a common Radio Dot system among multiple operators with one lead operator managing the system. While the company's Radio Dot product has taken share of the potential DAS opportunities in China, Asia and parts of Europe, its "multi-operator" version has not been widely adopted in North America where neutral host aspect of DAS is valued, and many system integrators view the system has too closely "tied" to the Ericsson ecosystem.

ExteNet Systems

ExteNet refers to itself as a "wholesaler" and sticks to a business model in which they design, build, own and operate both indoor and outdoor mobile infrastructure systems with its overall business over-indexed to the outdoor segment. The company utilizes DAS, small cells, remote radio heads, Wi-Fi, distributed core

networks, and sometimes a combination of these, to provide both indoor and outdoor systems. As a wholesale neutral-host operator, the company owns fiber and radio assets and operate networks on behalf of wireless service providers. The company has been known to offer unique system innovations such as carrying RF signals through air-conditioning vents inside buildings, resulting in less expense in cabling and installation. The company has installations in several high-rise buildings in key metro markets such as Willis Tower (formerly Sears Tower) in Chicago and the Empire State Building in NYC as well as convention centers, airports, and stadiums.

GS Teletech

With headquarter based in Korea, GS Teletech has a history of providing high-power outdoor and public safety repeaters for operators in Korea, Japan, and the U.S. With a history of delivering thousands of outdoor repeaters for SK Telecom, Softbank and Sprint, it has expanded product offerings into DAS and test equipment.

Huawei

Huawei has a long history of bringing small cell products to market especially China, SE Asia, and developing markets in other regions. With its LampSite product, Huawei has been very active in deployment of in-building wireless solutions. With its latest LampSite 3.0 solution which supports multi-operator capability, Huawei is bringing DAS features to address in-building wireless market opportunities, which is dominated by the traditional DAS architectures today.

JMA Wireless

JMA Wireless acquired Teko Telecom based in Italy on April 2013, and since then has been successful in penetrating large stadium projects in the USA. In addition to its TEKO DAS product, the company has announced its XRAN virtualized baseband product as well as CellHub to target the enterprise/CBRS segment and other venues that require scalable and dynamic resource allocation. With an increasing breadth of products ranging from antenna, DAS virtualized RAN, and millimeter wave radio via the PHAZR acquisition, and aggressive sales and marketing, the company has been gaining share in the DAS market.

KMW

Headquartered in Korea, KMW has a long history of manufacturing a wide range of telecommunication components and products including combiners, power amplifiers, antenna front ends, optical repeaters and connectors and cable assemblies. The company has been active in the millimeter wave radio developments in Korea and has partnerships with Tier-1 OEMs for macro-class products as well as indoor wireless units – notably RU development in partnership with Dali.

Mobilitie

Mobilitie is a privately-held wireless infrastructure company based in Newport, CA with regional offices across the USA. With a similar neutral-host business model as Boingo and ExteNet, Mobilitie design, build and operate indoor and outdoor mobile infrastructure utilizing DAS, Wi-Fi, and small cells. Some notable network installations include the Churchill Downs racetrack, MGM Resorts, sports stadiums and arenas, and shopping malls.

Radio Frequency Systems (RFS)

RFS is a global designer and manufacturer of cable, antenna and tower systems serving broadcast, wireless communications, land-mobile, and microwave industries. The company provides passive DAS and cabling systems for indoor wireless coverage solutions for 'hard to reach' places like underground tunnels. The company's RADIAFLEX 'leaky feeder' cable solution delivers RF coverage in confined spaces. The company also provides PIM-rated indoor antennas that support frequency bands ranging from 350MHz to 6GHz.The company is based in Germany with a worldwide presence.

SOLiD Technologies

SOLiD has grown its market share in the DAS market over the past few years, with an active sales presence in the USA. The company has fiber-based indoor DAS systems as well as high-power radio units (20W and 40W) for outdoor applications. The company has patented WDM fiber solutions which give them an advantage in fiber efficiency, especially for complex DAS installations. The company has announced its GENESIS platform in addition to its Alliance DAS solutions. It is developing several 5G indoor products which will be announced later this year or early next year.

Vertical Bridge

Vertical Bridge is a major private infrastructure provider for the wireless and broadcast industries. It currently has more than 55,000 sites nationwide, including 5,600 wireless and broadcast towers, 7,000 master lease rooftop and land assets and 43,000 billboards. It has recently partnered with Zinwave to offer in-building wireless "as a service" business model for the enterprise market whereby companies can sign up for "cellular as a service" OPEX service model.

Westell

Westell has refocused the company's market focus towards repeaters and the Public Safety market since seizing its ClearLink DAS product development. The company's in-building wireless business makes up a minority portion of its overall business and relies on its core site management and communication network solutions, including tower-mounted amplifiers, integrated cabinets, and power distribution.

Zinwave

As with some of the other companies above, Zinwave was acquired during early 2014 by McWane Inc., a diversified manufacturing company based in the USA. The company provides a fiber-based DAS system that can support cellular and public safety bands from 150MHz up to 2700MHz. With a new headquarter based in Dallas, Texas, the company has traditionally focused on the public safety and enterprise segments across some key verticals including healthcare, hospitality, and commercial real estate. The company has partnered with Vertical Bridge, a very large private communication infrastructure provider, to offer *Cellular-as-a-Service* in-building wireless connectivity service. The company has recently established a new US headquarter based in Dallas, Texas, with a new management team of veteran industry players. The company still maintains its research and development office in the UK and is active in the CBRS Alliance. The company plans to support the CBRS band with its DAS to target enterprise in-building market.

ZTE

ZTE leverages the DRS architecture similar to Huawei and Ericsson to address the in-building wireless opportunities. The company's DRS solution called Qcell has been deployed at China Telecom. Similar to other DRS vendors, ZTE plans to support 5G NR in the C-band for the Chinese operators who plan to massively deploy indoor systems in concert with its 5G Macro rollout.

ZyXel

Taiwan-based Zyxel introduced small-to-medium business-focused DAS and Repeater products at 2018 MWC Americas event. A key focus of the company's in-building wireless solution centers around the fact that they leverage the Cat-5 structured cabling. The company aims to target cost-conscientious enterprise segment with its low-power Remotes with a MIMO-capable "slim down" DAS headend. The company has a long history of providing telco-specific CPEs and networking gears and consumer-focused routers.

10. GLOSSARY

2G:	Second Generation Cellular
3G:	Third Generation Cellular
4G:	Fourth Generation Cellular
5G:	Fifth Generation Cellular
AHJ:	Authority Having Jurisdiction
BBU:	Baseband Unit
CAT-5:	Category 5 cabling (Ethernet cable standard)
CAT-6A:	Category 6 cabling (Ethernet cable standard)
CBRS:	Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US
CCI:	Crown Castle International
CLEC:	Competitive Local Exchange Carrier
CPE:	Customer Premise Equipment (e.g., cable modem, broadband gateway)
CPRI:	Common Public Radio Interface
CRAN:	Centralized RAN
CU:	Central Unit (ORAN functional unit handling higher-layer baseband)
CWDM:	Coarse Wavelength Division Multiplexing
DAS:	Distributed Antenna System
DRS:	Distributed Radio System (e.g., Ericsson's Radio Dot)
DU:	Distributed Unit (ORAN functional unit handling lower-layer baseband)
DWDM:	Dense Wavelength Division Multiplexing
EVM:	Error Vector Magnitude (metric highlighting modulation accuracy; lower % or higher decibel value implies better modulation)
GHz:	Gigahertz
GPP:	General Purpose Processor
GSM-R:	Global System for Mobile Communications—Railroad
I/Q:	In-phase and quadrature baseband signal

IDAS:	Indoor Distributed Antenna System
IF:	Intermediate Frequency
IFC:	International Fire Code
IP:	Internet Protocol (or Intellectual Property)
LAA:	License Assisted Access
LMR:	Land Mobile Radio
LTE:	Long Term Evolution
LWA:	LTE Wi-Fi Aggregation
MCPTT:	Mission Critical Push To Talk
MHz:	Megahertz
MIMO:	Multiple input, multiple output spatial multiplexing
mm-wave:	Millimeter wave
NEMA:	National Electrical Manufacturers Association
NFPA:	National Fire Protection Association
OBSAI:	Open Base Station Architecture Initiative
ODAS:	Outdoor Distributed Antenna System
ORAN:	Open RAN (an industry alliance to "open" RAN)
P25:	Project 25 (APCO-25 is a suite of standards for public safety digital radio communications for use in North America)
PAPR:	Peak-to-Average Power Ratio
PIM:	Passive Intermodulation
RAN:	Radio Access Network
RAU:	Remote Antenna Unit
RG-6:	Radio Grade 6 (a coaxial cable standard)
RF:	Radio Frequency
ROI:	Return on Investment
RRH:	Remote Radio Head
RU:	Radio Unit (ORAN functional unit handling PHY and RF)
TETRA:	Terrestrial Trunked Radio
TMA:	Tower Mounted Amplifier

UHF:	Ultra High Frequency (300MHz to 3GHz, but in most cases, refers to 300 MHz to 700 MHz bands)
VHF:	Very High Frequency (30 MHz to 300 MHz)
W:	Watts of power
Wi-Fi:	Wireless Fidelity (unlicensed wireless communications)

11. METHODOLOGY

To create estimates and forecasts for DAS equipment shipments, Mobile Experts relied on direct input from more than 20 industry sources, including input from multiple mobile operators contributing to the overall analysis to give a detailed global view of the market. Mobile Experts built a "top-down" forecast based on direct input from mobile operators and vertical markets, as well as overall trends in end-user demand for mobile services. Then, Mobile Experts built a "bottom-up" forecast through discussions with the supply chain, including integrators, neutral hosts, top-tier OEMs, DAS OEMs, and component suppliers. Mobile Experts also used financial disclosures from publicly traded companies to assemble a quantitative view of the equipment market.

Mobile Experts have defined market segments in a new way to achieve more clarity than other analysts in this area. This year, we have been able to collect meaningful data on DAS Revenue, with an ability to break out electronic equipment, cabling, and construction-related revenue.

Note that only DAS equipment is included in the market analysis, using a technical definition for DAS systems in which equipment is designed for multi-operator signals. It is important to note that this definition understates the total market for DAS neutral hosts and system integrators since these companies can work with either DAS systems, Remote Radio Heads, or Small Cells. (RRH and Small Cells are single-operator products). To illustrate how these companies have growth potential using non-DAS products, Chart 11 reflects the total market including Remote Radio Heads.

Definitions	Description
DAS	A Distributed Antenna System: A network of radio nodes for mobile communications, using a simulcast of identical RF waveforms from a hub.
Multi-operator	DAS systems configured to allow multiple mobile service providers to use the same distribution and radio nodes.
DRS	Distributed Radio System (a "deeper" C-RAN architecture where remote hub units distribute IF signal to multiple radio units, e.g., Ericsson's Radio Dot or Huawei's LampSite)
Small Cell	Network nodes which transmit less than 30W of composite power per sector, which include baseband processing for complete enodeB/nodeB/BTS functionality.
ODAS	Outdoor DAS nodes, transmitting 10W or higher composite power per node (power measured at the antenna port). Note that in rare cases a node with >10W power could be mounted indoors but we count it as "outdoor" based on power level.
IDAS	Indoor DAS, transmitting less than 10W of composite power per node. Note that some low-power nodes will be physically outdoors but are still categorized as "indoor" based on power level.
Remote Antenna Unit (RAU)	An RAU is a single DAS transmission/reception point. In the case of Active DAS this includes amplifiers, some signal processing, and the antenna
Active DAS	Active DAS systems use amplifiers at the remote antenna unit location
Passive DAS	Passive DAS systems use coaxial cable and no active components located at the antenna transmission point.
Dynamic DAS	Dynamic DAS has the ability to reallocate capacity between different remote antenna units during operation, shifting adaptively to adjust for traffic patterns.
Embedded DAS	Embedded DAS refers to a DAS system in which the signal sources are included in the product. The source does not need to be integrated at a PCB level, but simply integrated into one physical product.
Static DAS	Static DAS has a fixed allocation of capacity in each sector (in other words is not dynamic)
Equipment Revenue	Total equipment revenue includes the DAS hub, remote amplifier and antenna units, as well as cabling and accessories. Signal sources are not included. Cabling for outdoor DAS is not included.

Source: Mobile Experts

Figure 16. Definitions